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Final Report

INVESTIGATION OF TECHNIQUES FOR INVENTORYING FORESTED REGIONS

Volume I: Reflectance Modeling and Empirical Multispectral Analysis of Forest Canopy Components

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16. Abstract

This report documents three distinct but related studies of techniques that make use of remotely sensed data for forestry applications. Emphasis was placed on characteristics of forest canopy components, such as overstory and understory vegetation and the forest floor.

The first study applied the Suits' reflectance model for vegetation canopies to coniferous forests. Ground slope and aspect were added as parameters to the model which was then used to simulate 1260 different combinations of forest overstory, understory, and topographic position. Results were analyzed to gain insight into the fundamental capabilities and limitations of passive multispectral scanners (MSS) for identifying forest composition and conditions. Dense overstories effectively masked understories and dominated canopy reflectance. Sparse overstories exhibited great variability in reflectance which was attributable to the varying understory conditions. Effects were different in the different Landsat bands. Topographic variations degraded classification of dense canopies more than for less dense canopies, pointing toward the joint use of topographic and remotely sensed data. The impact of our modeling simple randomly oriented overstories instead of clumped overstories was found to be insignificant on these computed canopy reflectances. Recommendations are made for field measurements to validate and refine the model and for modeling of deciduous forest canopies for continued investigation of issues that are key to forest inventories.

The second study investigated the potential for inferring forest understory information on the basis of remotely sensed overstory conditions and ancillary information on site conditions. A literature review indicated that site information would provide a limited basis for inferring understory species composition, with some value gained from information on overstory density. On the other hand, the understory biomass production potential would be better inferred on the basis of overstory density, with improvement from the addition of site information. The combination of site information with remotely sensed overstory densities, in a common data base, could increase the amount of information about forest understories that is available for resource management decisions.

The third study addressed the utility of fine-resolution $(2m)^2$ MSS data for discriminating the component elements of forest canopies and for the classification of forest stands at a more general level. Spectral signatures from various canopy components differed substantially but yet were similar from stand to stand. High classification accuracy was achieved for individual component classes among the stands. In contrast to prior uses of conventional classification procedures on fine-resolution MSS data, high accuracy in classifying stands was achieved using a newly developed proportion space classification technique. The technique made use of the classified forest canopy spectral components (which may in themselves provide information in support of intensive forest management efforts). Application of the technique to fine-resolution MSS data, could be utilized in a multistage sampling approach for inventorying forest and rangeland resources. Recommendations are made for further development of the technique and related training procedures. Also, the evaluation of active (laser and radar) sensors in forestry applications is recommended.

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PREFACE

This document reports processing and analysis efforts on one task of a comprehensive and continuing program of research in multispectral remote sensing of the environment. The research is being carried out for NASA's Lyndon B. Johnson Space Center, Houston, Texas, by the Environmental Research Institute of Michigan (ERIM). The basic objective of this program is to develop remote sensing as a practical tool for obtaining extensive environmental information quickly and economically.

The specific focus of the work reported herein was on forestry applications of remote sensing. It constitutes work on one subtask of a two-part effort under the Forestry Applications Program (FAP), a joint Program of NASA and the U.S. Forest Service, with Headquarters at the Johnson Space Center, The other subtask is reported in Volume II, ERIM 122700-35-F_2, entitled, "Forestry Information System Requirements and Joint Use of Remotely Sensed and Ancillary Data", by R. C. Cicone, W. A. Malila, and E. P. Crist.

The research covered in this report was performed under Contract NAS9-14988 during the period 15 May 1976 to 14 Nov 1977. Mr. I. Dale Browne (SF3) served as the NASA Contract Technical Monitor, Dr. David Amsbury (SF5) was NASA Task Monitor, and Dr. F. P. Weber (SF5) was the cognizant USFS Representative. At ERIM, the work was performed within the Infrared and Optics Division, headed by Richard R. Legault, Vice-President of ERIM, in the Information Systems and Analysis Department, headed by Dr. Quentin A. Holmes. Mr. Richard F. Nalepka, Head of the Multispectral Analysis Section served as Principal Investigator and Dr. William A. Malila as Task Leader.

The authors wish to acknowledge the assistance of other members of the ERIM staff in addition to those cited above. Dr. G. H. Suits was consulted on the adaptation and use of his vegetation canopy bidirectional reflectance model. J. M. Gleason incorporated slope and aspect parameters into our implementation of the model, with guidance from Dr. Suits. R. C. Cicone and E. P. Crist provided support for the model calculations. R. Nalepka contributed to the conceptualization and evaluation of the proportion-space classification technique. Ms. D. Dickerson, along with Ms. E. Hugg, M. Warren, and J. Watters, provided efficient and accurate typing support throughout the contract period and for this report.

CONTENTS

CONTENTS (CONT.)

FIGURES

FIGURES (Cont'd)

TABLES

1
SUMMARY

This report documents the methods and results of three distinct but related studies designed to investigate, develop, and evaluate techniques that make use of remotely sensed data for forestry applications. Emphasis was placed on investigating characteristics of forest canopy components such as the overstory and understory vegetation, and the forest floor. The overall objective was to develop insight into the utility of passive multispectral scanner data for providing detailed inventory information about specific overstory/understory conditions that may be required by forest managers. Specific objectives of each study were as follows:

- Modify an existing vegetation canopy reflectance model to simulate forest canopy bidirectional reflectance properties. Use the model to examine the relative importance of various forest canopy component characteristics on remotely sensed data;
- Investigate the potential for inferring the type and condition of forest understories on the basis of overstory conditions and ancillary data;
- Investigate the discriminability and potential usefulness for multispectral signatures of various forest canopy components in high-resolution multispectral scanner data.

The study of forest canopy reflectance modeling was designed to demonstrate the application of an existing mathematical reflectance model for vegetation canopies to a forestry application and to illustrate its potential for analyzing trends that might provide insight into the fundamental capabilities and limitations of remote sensors for identifying forest composition and condition. Initially, the reflectance model was modified to incorporate ground slope and aspect as additional parameters. We then utilized the model to compute Landsat reflectance

values for a variety of simulated coniferous forest canopy overstory/understory situations that might be found in the Western U.S. The two-layer model was utilized to model canopy situations, with the top layer representing one of several overstory densities and the bottom layer representing one of several understories. In order to help establish the extent to which Landsat can provide direct information about vegetation conditions that occur beneath forest overstories, a wide variety of understory situations were examined. Three distinctive base materials (needle litter, rock rubble, and a burned surface) were covered by grass understories and brush understories of varied densities, ranging from 0 to 100% ground cover. These in turn were covered by pine overstories of four densities (zero, sparse, medium, and dense) having percent ground covers of 0, 27, 47, and 72%, respectively. A total of 84 unique overstory/understory situations were simulated, each at 15 different topographic variations for a total of 1260 cases.

Results of model calculations illustrate the capability of forest canopy reflectance modeling to quantify and examine the relative importance of various forest canopy properties and canopy orientations on remotely sensed (Landsat) data. In particular, the effects of increasing vegetation density on canopy reflectance are shown to differ rather dramatically depending on spectral band, base material, and vegetation type. Although most completely exposed understories were differentiable, only the sparse overstory situations produced sufficient variation in reflectance as a function of understory condition to offer hope of direct Landsat sensing of understory conditions. Furthermore, the importance of properly accounting for canopy slope and aspect orientation was demonstrated by the variability in the simulated values.

Additional aspects of the study include a quantification of the discriminability of various overstory/understory situations; a simulation method was used to help establish the extent to which Landsat can provide direct information about vegetation conditions that occur beneath forest canopy overstories. The impact on the computed canopy reflectances, of modeling clumped overstories instead of the simple randomly oriented overstories used in the majority of our study, was examined and found to be insignificant. Field measurements are recommended for reflectance model validation and refinement for coniferous forests. Application of reflectance modeling to deciduous forests is also recommended. These would enable the continued investigation of issues key to forest inventories, using the modeling approach.

The second study investigated the potential for inferring understorv information on the basis of remotely sensed overstory conditions and ancillary information on site conditions. Our method of investigation consisted of a literature review and analysis. It was concluded that the inference of understory species composition on the basis of remotely sensed overstory properties alone is unreliable. Site information may provide a better basis for inferring understory density. On the other hand, the understory biomass production potential would be better inferred on the basis of overstory density, with improvements likely from the addition of site information. The combination of site information, obtained from ancillary sources, with forest overstory densities, provided by remote sensors, in a common data base, could provide means for increasing the amount of information about forest understories that is available for making resource management decisions.

The third study initially investigated the discriminability of various forest canopy components in fine-resolution MSS data and, subsequently, demonstrated the potential for proportions of classified canopy components to provide improved forest stand classification. Airborne MSS data utilized for this study were collected on 20 Nov 74 from an altitude of 610 meters (2000 feet) over the Sam Houston National Forest in East Texas. The spatial resolution was approximately $(2m)^2$.

A total of 24 signatures were computed for individual spectral components that were observed within five forest stands. A wide complexity of spectral detail was noted within the forest canopies, caused chiefly by the existence of different types of tree crowns, the contrast of the understory with overstory, and, very significantly, the occurrence of shadows within the canopies. Analysis of the signatures indicated similar types of canopy components can exhibit very similar spectral properties from stand to stand -- thus explaining the significant overlap that can occur among the multivariate distributions of forest stand signatures computed in a conventional fashion from fine resolution data.

An aggregated set of eight signatures, each representing a different spectral class of components common to all stand areas, exhibited a good capability for classifying the major components of forest canopies. Overall classification accuracy for resolution elements of canopy components that had been selected for signature computation exceeded 80% for the set of eight spectral classes and surpassed 90% when two spectral classes within each of the pine and hardwoods categories were combined. The capability to classify the components of forest canopies could assist in providing necessary information to support intensive forest management efforts.

Finally, by making use of the proportions of all classified canopy components, we devised a new proportion-space technique for classifying forest stands at a more general level of detail. The technique provided for a markedly improved overall forest stand classification accuracy of 76% with fine resolution data; the employment of conventional classification had resulted in only 40.5% accuracy. The capabilities of fine resolution data for providing both detailed and general levels of information could be advantageous in multistage sampling surveys of forestry and rangeland resources, and we recommend development of techniques to realize those capabilities. This recommendation includes canopy component signature extraction techniques such as clustering, classification techniques such as the proportion-space technique, and assessment of the potential of existing active (laser and radar) sensors.

2
INTRODUCTION

With the passage of the Multiple Use and Sustained Yield Act of 1960, increased emphasis has been placed on the multiple use aspects of the nation's forest reserves. Competition for the use of forest land has increased substantially, given the increased demand for forage and increasing public desires for outdoor recreation areas. Many of the decisions regarding the allocation of uses for forested regions require information on the minor vegetation components of the forest. Furthermore, the National Environmental Policy Act of 1969 and the Forest and Rangeland Renewable Resources Planning Act of 1974 underline the need to assess the understory vegetation components of the forest, as well as the overstory. Thus, there is a need to inventory, monitor, and update information regarding all components of forest stands to provide inputs for multiple-use management programs.

The overall objective of the three distinct but related studies reported herein was to investigate, develop, and evaluate techniques that make use of remotely sensed data for forestry applications. These applications include mapping forested regions and assessing forest canopy components such as the overstory and understory vegetation, and the forest floor.

Specific objectives of each study were as follows:

- Modify an existing vegetation canopy reflectance model to simulate forest canopy bidirectional reflectance properties. Use the model to examine the relative importance of various forest canopy component characteristics on remotely sensed data.
- Investigate the potential for inferring the type and condition of forest understories on the basis of overstory conditions and ancillary data.
- Investigate the discriminability and potential usefulness for multispectral signatures of various forest canopy components in fine-resolution multispectral scanner data.

Emphasis was placed on investigating characteristics of forest canopy components in order to develop insight into the utility of passive multispectral scanner data for providing detailed inventory information about specific overstory/understory conditions that may be required by forest managers. Detailed descriptions of each study are presented in Sections 3, 4, and 5, respectively.

3
ANALYTICAL MODELING OF FOREST CANOPY REFLECTANCE

A complete assessment of the potential of remote sensing for inventorying forests and their respective canopy components requires knowledge of the spectral and spatial (e.g., horizontal and vertical structure) characteristics of forest canopies and their components; knowledge of their respective phenologies, growth characteristics, and dependencies on site conditions; and an understanding of how these characteristics affect remote sensor signals. One can investigate these various phenomena through direct observation, experimentation, and measurement, or through mathematical modeling and simulation.

A mathematical model that describes forest canopy reflectance incorporates the interactions of various canopy component characteristics with incoming radiation and thus enables computing the resultant signal for a particular remote sensor. Such models allow one to select individual component characteristics, examine greater ranges of parameter values than are practical empirically, and to determine the relative importance of the various factors that affect spectral responses. Therefore, canopy reflectance models offer the potential for analyzing trends that might provide insight into the fundamental capabilities and limitations of remote sensors for identifying and assessing some forest canopy situations.

A vegetation canopy reflectance model has been developed at ERIM by Dr. Gwynn Suits and used to analyze agricultural crops and natural grasses [1-5]. In this study, new features and capabilities were added to make the model more directly applicable to a forestry application. We then utilized the model to compute Landsat reflectance values for a variety of simulated coniferous forest canopy overstory/understory situations that might be found in the Western U.S. Finally, we analyzed the model results to determine the effects of various parameters on canopy reflectance.

3.1 MODEL DESCRIPTION AND MODIFICATION

The Suits canopy reflectance model enables the calculation of vegetation canopy bidirectional reflectance by requiring as inputs a number of variables which define the spectral properties of the component materials and background, the structure of the canopy, and the illumination/observation angle geometry. Specifically, bidirectional spectral reflectance is made traceable to a mathematically represented idealized canopy requiring eight types of input parameters. Spectral reflectance and transmittance values for canopy components and background spectral reflectance account for the spectral properties of the biological materials and the base material. Sun and view angle from zenith, and view azimuth relative to the sun define the illumination/observation geometry. Finally, canopy structure is idealized by replacing the actual components with in situ measurements or estimates of their area projections onto horizontal and vertical planes. When accumulated for the various kinds of component biological materials, the horizontal and vertical component area projections become synonymous with horizontal projected leaf area index and vertical projected leaf area index, respectively.

The model provides for the complex character of most canopies by allowing the designation of one to three layers within the canopy, each containing varied amounts of several spectral classes of biological materials in accordance with their respective structural specifications. For this study, two layers were utilized, in order to simulate the separate overstory and understory regions of forest canopies.

The initial form of the Suits model assumed a horizontal base for the structure of the canopy. However, many forests occur in regions of variable topography that contributes additional influences on canopy reflectance. The forested test site in Grand County, Colorado, for which the processing and analysis of Landsat data is reported in Volume II of this report [6], provided one such example that was of particular interest. The desire to investigate topographic influences on canopy reflectance from an analytical standpoint required modification of the model. Therefore, ground slope and aspect were incorporated as parameters in the model, following relationships defined by Suits.

A set of parametric calculations was conducted using the modified model to examine the effects of slope and aspect on Landsat inband reflectance values for pine canopies. Specifications for the canopy characteristics and ground orientations used are described in Section 3.2.

Figure 1 illustrates the effect of slope on the computed reflectance in Landsat Band 6 of both a perfectly diffuse surface and the pine canopy; on the right side of the figure the slopes were facing toward the sun and, on the left side, away from the sun. If the perfectly diffuse reflecting surface were tilted from the horizontal to a position facing toward the sun, the irradiance (incident power per unit area) on the surface would increase; the net effect would be the same as that caused by an increase in reflectance of the horizontal diffuse surface. Conversely, the equivalent horizontal reflectance would decrease as the surface was tilted away from the sun, as shown in Figure 1. Comparable calculations for the pine canopy show that it

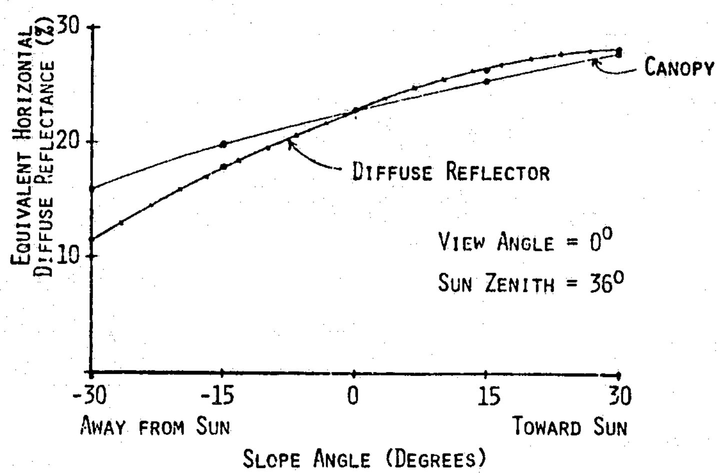


FIGURE 1. ILLUSTRATION OF NON-DIFFUSE NATURE OF CALCULATED REFLECTANCE FOR A SLOPING PINE CANOPY (Landsat Band 6)

has a non-diffuse characteristic and a lesser slope effect, as is shown in Figure 1. In other words, the model predicts that variations on signals due to terrain slope and aspect effects would be less for forested areas than for diffuse surfaces.

With the slope angle fixed at 30°, the effect of aspect (i.e., azimuthal direction of the slope) on the magnitude of Landsat reflectance (Band 7) is illustrated in Figure 2 for two sun angles representative of August and November Landsat acquisition dates over the Grand County, Colorado, test site. As one might expect, the overall aspect effect is greater for the larger sun zenith angle (lower sun elevation angle).

Finally, a comparison of the reflectance values of Figure 1 was made to actual 15 August 73 Landsat Band 6 signals extracted from the Grand County site, specifically, from the Fraser Experimental Forest within the Arapaho National Forest. Terrain slope and aspect data were procured in digital format from the Defense Mapping Agency and registered to the Landsat data, as described in Volume II [6]. Sample

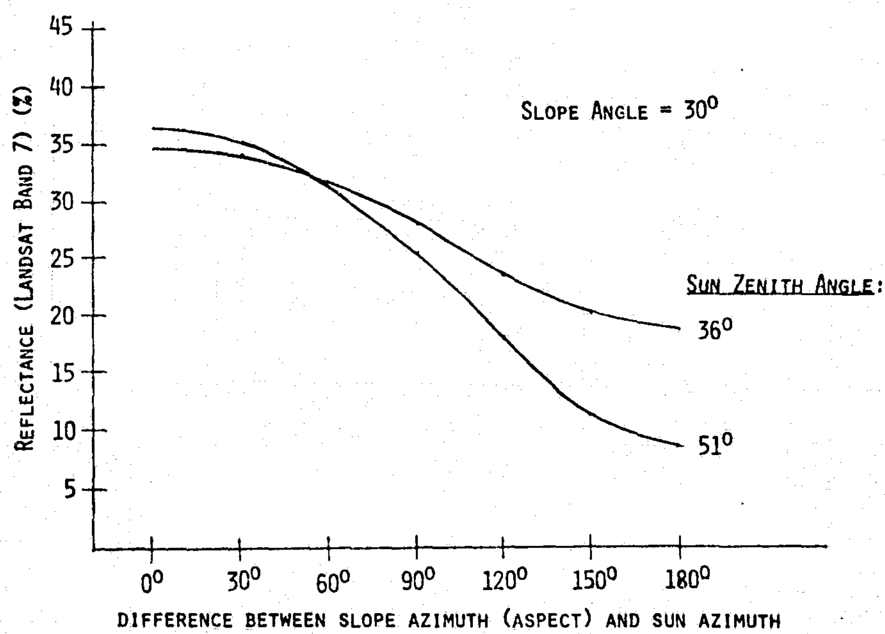


FIGURE 2. ILLUSTRATION OF SLOPE ASPECT EFFECTS ON PINE CANOPY REFLECTANCE

Landsat means were calculated for selected Lodgepole pine stands having the appropiate slope and aspect variables. These values are plotted as X's on Figure 3, against the right-hand scale (no normalization was performed). Note that these empirical values tend to match the calculated non-diffuse sloping canopy characteristic more closely than the characteristic of the perfectly diffuse reflector.

3.2 SIMULATION PROCEDURE

Because of the related empirical analysis of Landsat data for the Grand County test site reported in Volume II [6], our objective for modeling forest canopies was to compute Landsat signals for a variety of coniferous overstory/understory situations that might be found in the Western United States.

This section describes the procedure by which various components of our modeled forest canopies were specified.

3.2.1 CANOPY PARAMETERS

A two-layer model was employed, as illustrated in Figure 4. The top layer represented the tree overstory, while the bottom layer

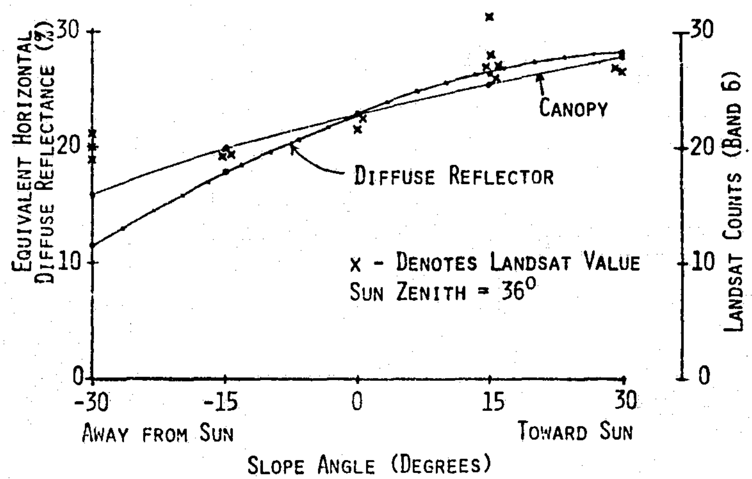


FIGURE 3. COMPARISON OF TREND IN LANDSAT SIGNALS FROM LODGEPOLE PINE STANDS IN FRASER EXPERIMENTAL FOREST WITH MODEL-COMPUTED REFLECTANCE VALUES

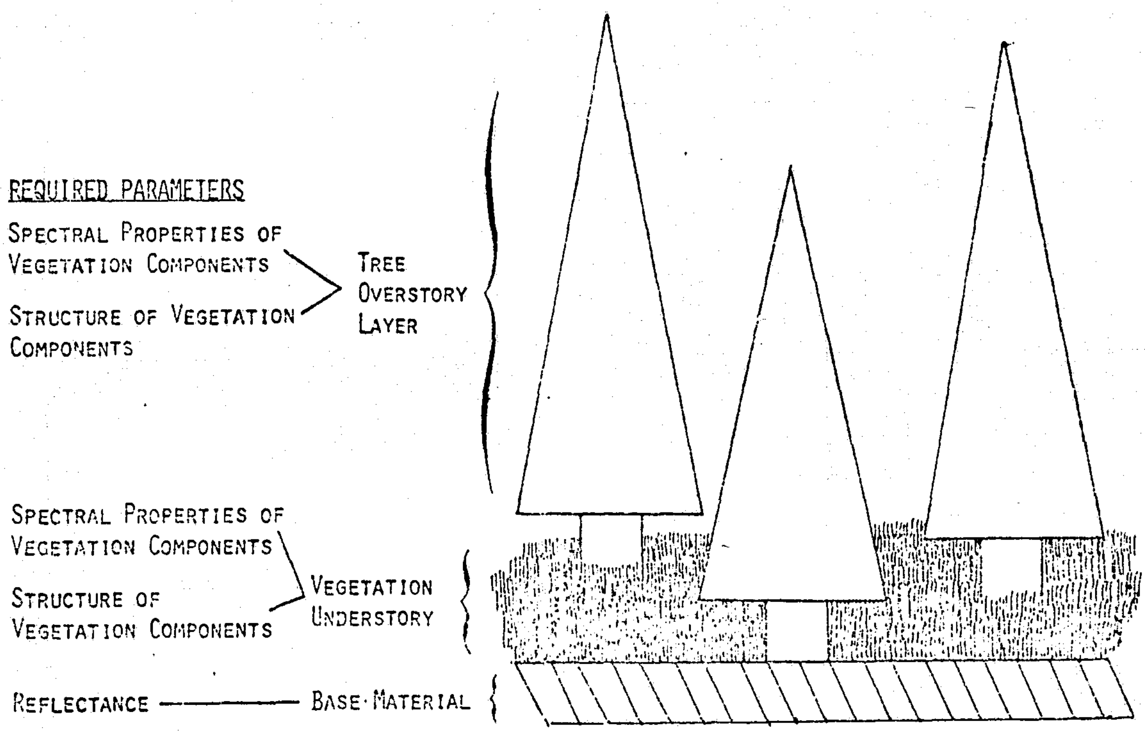


FIGURE 4. ELEMENTS OF FOREST CANOPY REFLECTANCE MODELING

represented the vegetation understory. Both of the layers and the base materials were specified by spectral and structural characteristics extracted from the literature and measurements by various investigators.

3.2.1.1 CANOPY BASE MATERIALS

Three types of surfaces were specified as the bases upon which all overstory/understory situations could potentially occur. These included needle litter, rock rubble, and a fire-blackened surface. Specification of these materials to the model required only hemispherical spectral reflectance values. All surfaces were assumed to be flat (without structure).

Hemispherical spectral reflectance for needle litter was taken from in situ measurements collected by Fox [7]. For rock rubble, spectral properties reported by Nazare [8] for weathered schist were utilized. Spectral reflectance for a burned surface was assumed to be a uniform 5%.

3.2.1.2 UNDERSTORIES

The understory situations which were simulated ranged from entirely exposed base material through three increasing densities of grass and three densities of brush vegetation. The three densities are stated in terms of ground cover in Figure 5.

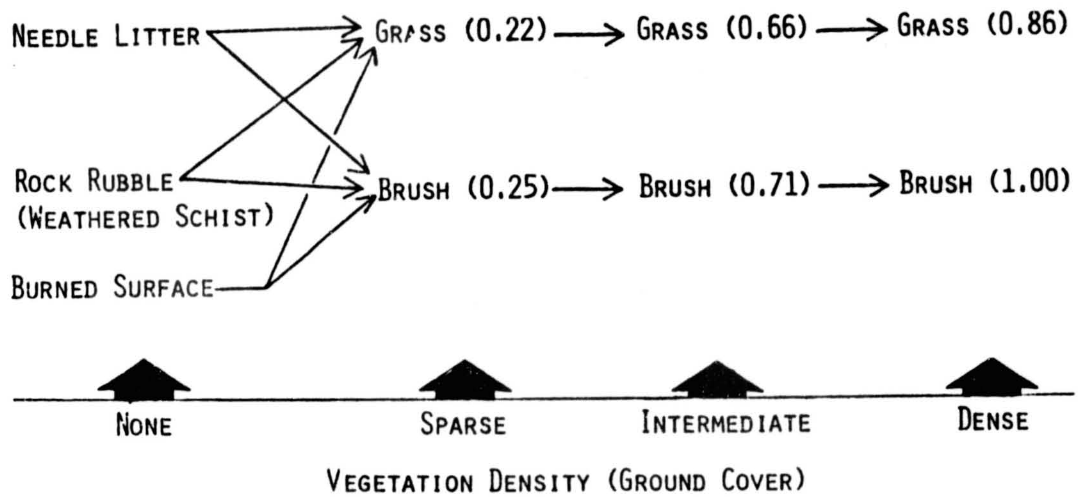


FIGURE 5. MODELED UNDERSTORY SITUATIONS

Quantification of structural parameters for the grass and brush vegetation assemblages was based on <u>in situ</u> measurements of vegetation structure reported by Sadowski [5]. Table 1 provides the composition for the grass and brush assemblages. Spectral reflectance and transmittance characteristics for green leaves was taken from Sadowski [5], dead leaf spectra from Colwell [9], and woody stem spectra from the National Academy of Sciences [10].

TABLE 1. UNDERSTORY COMPOSITION BY SPECTRAL CLASS

Understory	Spectral Components	Percent
Grass	Green Leaves	0.80
	Dead Leaves	0.20
Brush	Green Leaves	0.70
	Woody Stem Material	0.30

3.2.1.3 OVERSTORIES

Four densities of tree overstory were placed over each understory, as illustrated in Figure 6. A total of 84 different combinations of base material, understory, and overstory were thus simulated.

Structural parameters and spectral reflectance and transmittance characteristics for overstories were based on measurements made by Fox [7] for a stand of Jack Pine (Pinus Banksiana) in Southern Michigan. We varied the measured structural parameters of the dense overstory to simulate intermediate and sparse densities. Table 2 provides the composition of the pine overstories.

TABLE 2. PINE OVERSTORY COMPOSITION BY SPECTRAL CLASS

Spectral Components	Percent
New Needles	0.125
Old Needles	0.500
Branches and Boles	0.375

3.2.1.4 TERRAIN VARIATIONS

To simulate the effect of slope and aspect variations on canopy reflectance, each of the 84 overstory/understory situations was allowed to assume slope positions of 0°, 15°, and 30°. Slopes of 15° and 30° were rotated through azimuths of 0° to 180° (in 30° increments) relative to the sun, with 0° slope azimuth defining the "toward sun" direction. Thus, a grand total of 1260 unique combinations of overstory,

UNDER-STORIES \ OVER-STORIES	No Overstory (0.00)*	Sparse Pine (0.27)*	Intermediate Pine (0.47)*	Dense Pine (0.72)*
Exposed Needle Litter	✓	✓	✓	✓
Litter & Grass (3 Densities)	✓	✓	✓	✓
Litter & Brush (3 Densities)	✓	✓	✓	✓
Exposed Rock	✓	✓	✓	✓
Rock & Grass (3 Densities)	✓	✓	✓	✓
Rock & Brush (3 Densities)	✓	✓	✓	✓
Exposed burned surface	✓	✓	✓	✓
Burned & Grass (3 Densities)	✓	✓	✓	✓
Burned & Brush (3 Densities)	✓	✓	✓	✓

NOTE: * Overstory ground cover.

FIGURE 6. COMBINED OVERSTORY/UNDERSTORY SITUATIONS MODELED

understory, and topographic position were simulated for coniferous forest canopies.

3.2.1.5 SUN AND VIEW GEOMETRY

A sun zenith angle of 36° was chosen; it represents conditions on an August Landsat acquisition date over western Colorado. A nadir view angle was assumed.

3.2.1.6 MODELING THE CLUMPED NATURE OF FOREST OVERSTORIES

A question which arose in applying the Suits canopy reflectance model to forests is its assumption that canopy components are distributed within each canopy layer in simple random fashion. The model assumes that leaves are distributed so as to be located equally likely in any position within a layer in accordance with their concentration in that layer. This random distribution allows for the occurrence of occasional clumps of leaves with a predictable frequency, a situation perhaps best represented by grass canopies that contain more or less uniformly distributed components. However, it may not simulate a situation that exhibits a distribution more clumpy than would be expected by the equally likely placement of a simple random distribution. A forest canopy represents such a situation in that leaves and branches are associated with tree crowns as a clump with larger voids between crowns.

At issue is whether the assumption causes computed canopy reflectance values to differ appreciably from reflectance values that might be realized if structural components were distributed in a more clumpy fashion. We, therefore, developed a method for representing clumped spatial characteristics of forest overstories within the Suits canopy reflectance model. Reflectance values computed for the new canopies with clumped overstories were then compared to reflectance values obtained for canopies with assumed randomly oriented overstory components.

We decided that it would be most appropriate to hold percent cover fixed in our examination of the effects of clumpy overstories. Thus, the structures specified for the sparse, intermediate, and dense coniferous overstories were not changed for this simulation of clumped component distribution. Rather, clumped components were represented in the model by replacing some proportion of components of single thickness with components of double thickness having appropriately different spectral reflectance and transmittance properties. In this way, the influences of clumped component distributions on canopy reflectance were believed to be properly represented by the radiometric effects of overlapping components and not by changes in percent cover.

Initially, a proportion of the single components in each spectral class of components that might be expected to exhibit overlap within the overstory was designated. Proportions were designated for the new and old needle component material and horizontal branch material. Vertically oriented stem material was not allowed to overlap. New radiometric properties, defined by Dr. G. Suits and based on energy interactions for stacked double components, were then introduced for the overlapped components of each spectral class. Finally, modeled canopy reflectance values were recomputed for two degrees of overlap in which first 50 percent and then 100 percent of the allowed single components in each spectral class were replaced with double components. The results are presented in Section 3.3.1.

3.2.2 MODEL REFLECTANCE SPECTRA CONVERTED TO LANDSAT INBAND REFLECTANCE

The model was used to compute reflectance spectra for all modeled forest canopy situations at 10 nm intervals between 400 and 1100 nm -- consistent with the precision at which canopy component and base material spectra were specified in the model. Each canopy spectrum was then converted to four Landsat inband reflectance values by multiplying model-computed reflectance by the appropriate Landsat spectral response at each 10-nm interval and integrating the results between the limits of each band.

3.3 RESULTS

This section first presents results of our analysis of the possible impact of clumped overstories on our modeled canopy reflectances. Next, the capability of forest canopy reflectance modeling to quantify and examine the relative importance of various forest canopy properties and canopy orientations on remotely sensed (Landsat) data is illustrated. Lastly, the discriminability of various overstory/understory situations is evaluated to help establish the extent to which Landsat can provide direct information about vegetation conditions that occur beneath forest canopy overstories.

3.3.1 THE IMPACT OF CLUMPED OVERSTORIES ON CANOPY REFLECTANCE

In Figure 7, reflectance model results for the two degrees of increased component overlap that were simulated within the pine canopy overstories are compared with the standard model assumption of simple random component overlap. Canopy reflectance values are represented for all three previously structured overstory densities with a common understory of entirely exposed rock rubble.

For Band 5, no change in canopy reflectance occurs as components progressively overlap. Slight decreases are noted for Band 7. These decreases are attributed to the transmittance properties of needle components in Band 7 where the moderate needle transmittance (~14%) and high reflectance (~60%) causes increased first-surface reflectance and decreased two-surface transmittance as needles overlap. Thus, within the canopy, overlapped needles will display enhanced reflectance and cast darker shadows. Branch material was opaque in all spectral regions. In Band 5, the lack of needle transmittance results in no change in first-surface needle reflectance and two-surface needle transmittance for overlapping needles, thus producing no corresponding change in canopy reflectance. Note that the effect of darker shadows for overlapping needles in Band 7 apparently outweighs the enhanced first-surface reflectance by reducing overall canopy reflectance.

For the coniferous overstories simulated here, this illustration of the effect of clumpiness among the structural components within the reflectance model produced a relatively inconsequential change in computed canopy reflectance. Clumped components would most likely produce greater changes in computed reflectance for canopies having components with high transmittance properties, such as leaves of deciduous trees. Accounting for clumped components within the reflectance model might be appropriate on a routine basis in such situations. However, for these coniferous overstories, we judge that the negligible effects of clumped component distribution on model-

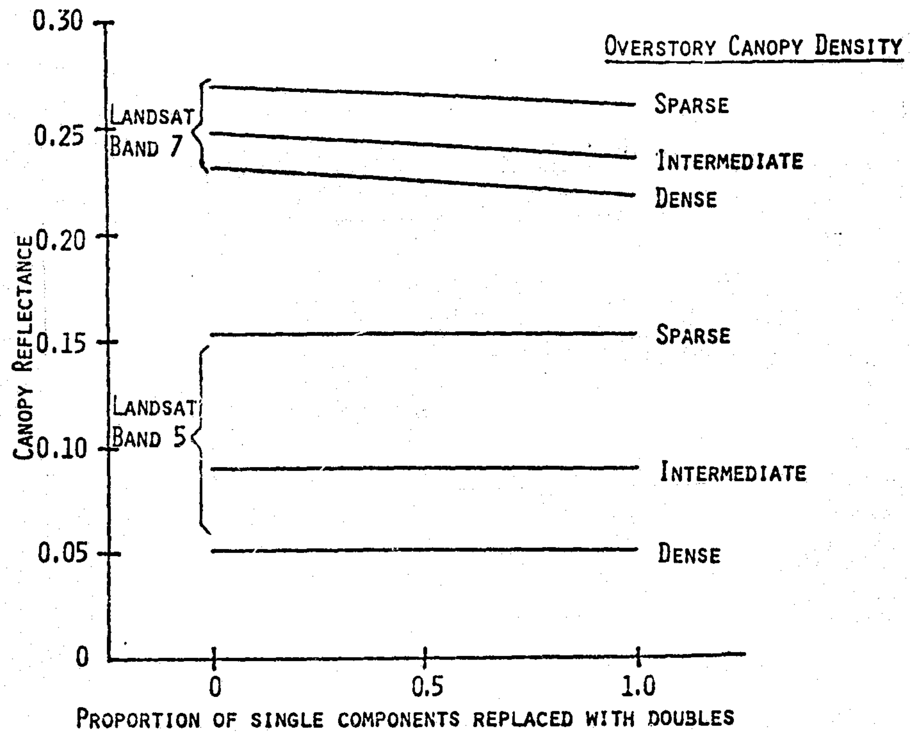


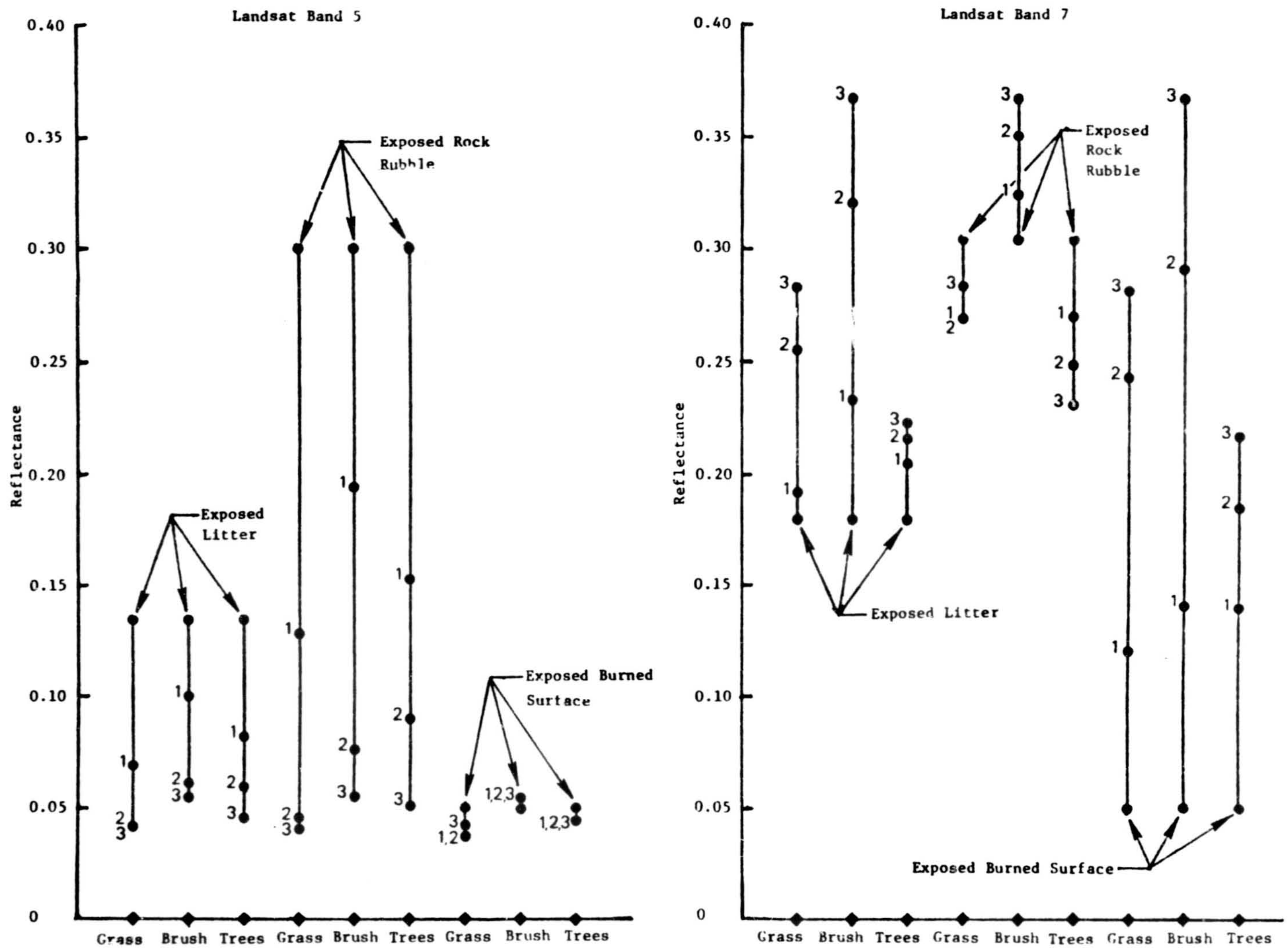
FIGURE 7. MODELED FOREST CANOPY REFLECTANCE RESULTS FOR CLUMPED CANOPIES

computed canopy reflectance would not affect the results and conclusions of canopy modeling presented next, which were generated using the simple random distribution assumption.

3.3.2 EFFECTS OF VARIOUS PARAMETERS ON CANOPY REFLECTANCE

The effects of the various canopy variables on reflectance were first examined for individual Landsat Bands 5 and 7. Figure 8 shows the isolated effects on canopy reflectance of each of the three types of vegetation taken individually. Varying densities of the three vegetation types are shown over litter, rock rubble, and burned bases. All non-vegetated base materials have widely separated reflectance values in each band.

The effects of increasing vegetation density on canopy reflectance differ rather dramatically depending on spectral band, base material,



NOTE: Vegetation Density
1. Sparse
2. Intermediate
3. Dense

FIGURE 8. EFFECT OF VARIATIONS IN INDIVIDUAL CANOPY VARIABLES ON CANOPY REFLECTANCE

and vegetation type. For Landsat Band 5, the vegetation was darker than the exposed rock rubble and litter. The rates at which the reflectance decreased with intermediate levels of density varied as a function of vegetation type, principally due to different canopy structures. The leaves in the grass canopy were oriented primarily in a vertical fashion, while the brush leaves were primarily horizontal; the trees were intermediate. (The primarily vertical orientation of the grass would contribute to the existence of the greatest proportion of shadowed area cast by the sun within the canopy, thus causing the increased rate of reflectance decrease with greater vegetation density.) Note, for all vegetation types, the greater sensitivity of reflectance to initial changes in vegetation density with decreased sensitivity occurring for denser vegetation. Reflectance values for dense vegetation were all quite similar, having no influence of base material and indicating little capability for differentiating vegetation types. Lack of contrast between vegetation and the burned surface in Band 5 resulted in no change in reflectance with varying vegetation density.

Differences between vegetation types were more apparent for Band 7. The reflectance values for the dense canopies were quite different, with the horizontally oriented brush canopy having the highest and the tree canopy the lowest. Again, the reflectance of dense cover of each type was independent of base material, but the patterns of reflectance as a function of cover density were more distinctive than for Band 5. The burned surface and exposed litter had a lower Band 7 reflectance than any of the vegetation types, so increasing density raised the total reflectance. Rock rubble, on the other hand, had a Band 7 reflectance that was higher than grass or trees but lower than brush. Note that the addition of sparse or intermediate grass covers to the rock rubble lowered the Band 7 reflectance but further increases in density caused a rise in canopy reflectance.

The joint effects on Bands 5 and 7 of overstory/understory combinations are displayed in Figure 9. Increasing densities of the

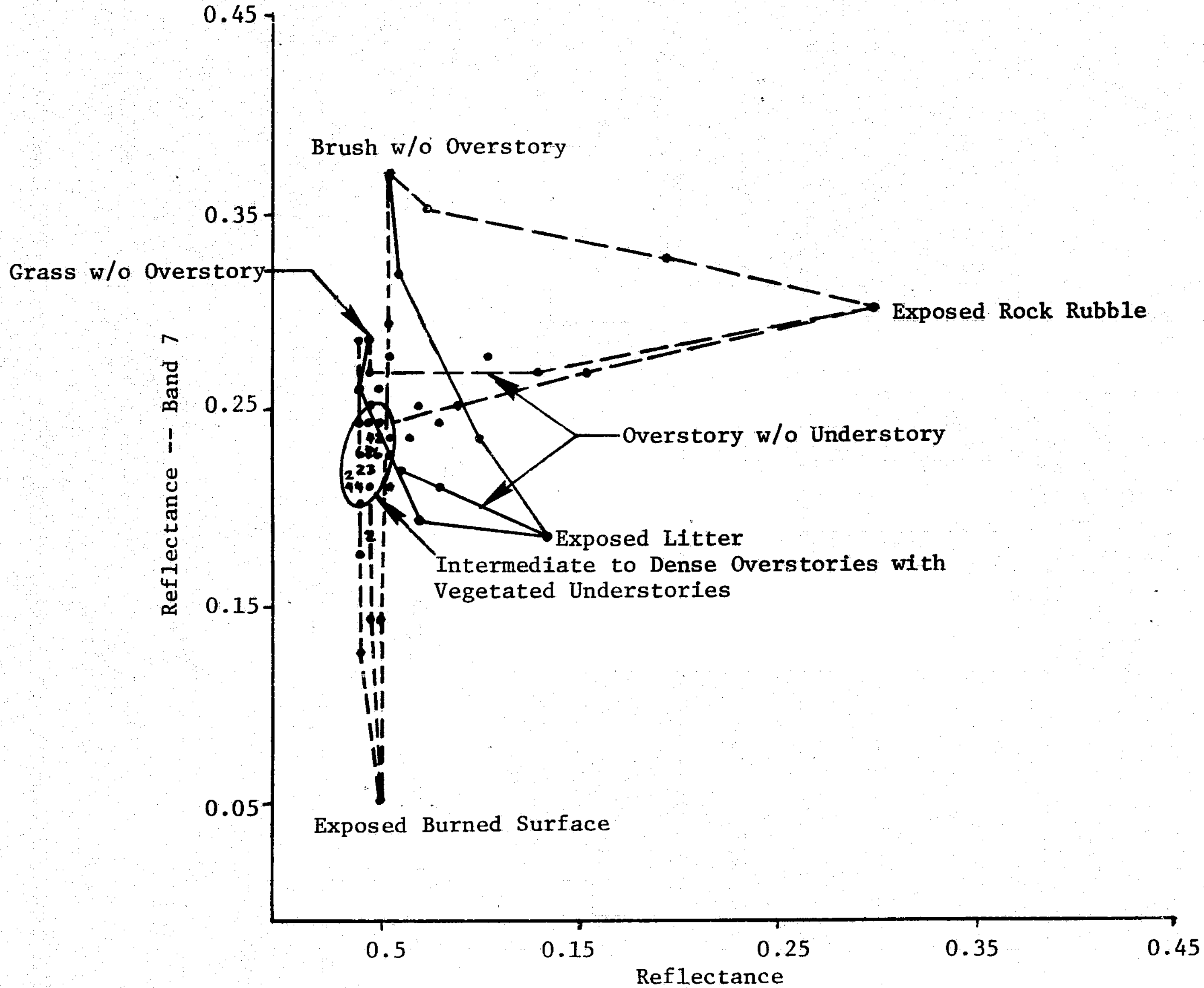


FIGURE 9. EFFECT OF COMBINED OVERSTORY/UNDERSTORY SITUATIONS (HORIZONTALLY ORIENTED CANOPIES)

three vegetation types taken individually are traced from each exposed base material. The region enclosed by the ellipse contains values associated with intermediate to dense overstories having vegetated understories. The figure clearly indicates that the dominant effect of overstory on masking understory vegetation spectral properties.

Situations of sparse overstory with varied densities of understory are indicated separately in Figure 10. The ellipse containing reflectance values for all intermediate to dense overstory situations is again indicated. It is obvious that several understory situations, although well separated from the ellipse when unobstructed by the effect of overstory (Figure 9), become undifferentiable from the more heavily forested areas when partially obstructed by only sparse overstory. Reflectance values lying outside the ellipse suggest situations where there is some hope for direct Landsat sensing of understory conditions.

The importance of knowing the slope and aspect orientation of a forest canopy, before trying to deduce or extract information on its components, is illustrated in Figure 11. In this figure, reflectance values for all computed variations of slope and aspect are indicated for several combinations of base material, overstory, and understory. The exposed base materials remained distinctive, but as more vegetation was added, the reflectance values began to overlap, making differentiation of some non-forested situations from densely forested situations very difficult. Figure 12 illustrates the variations in reflectance values for the sparse overstory situations positioned on a horizontal plane and on 30° slopes facing toward and away from the sun. Slight differences in reflectance, caused by varying understory conditions, that occur on flat terrain are radically changed by the effects of slope and aspect.

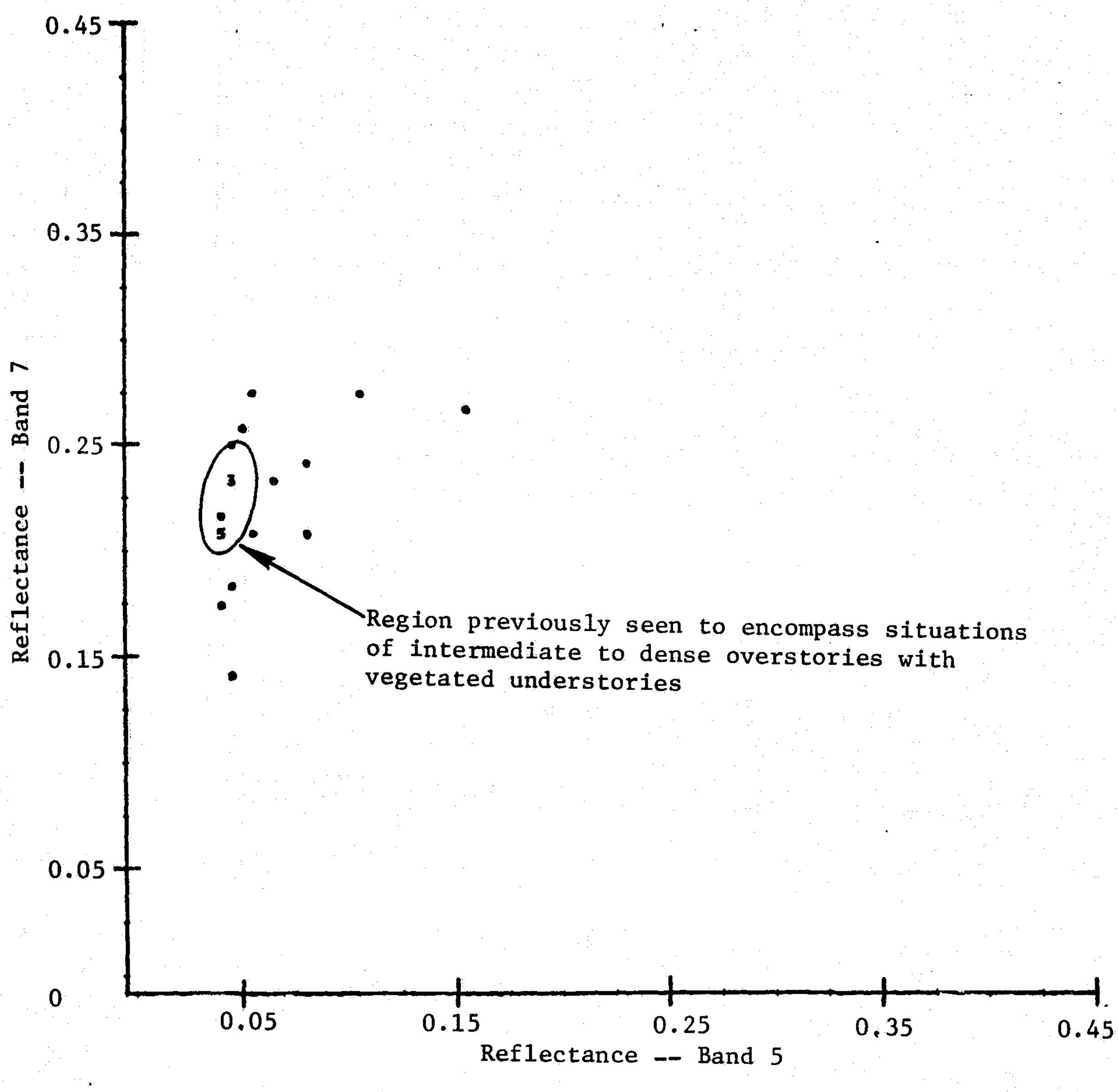


FIGURE 10. CANOPY REFLECTANCE FOR SITUATIONS OF SPARSE OVERSTORIES (Horizontally Oriented Canopies)

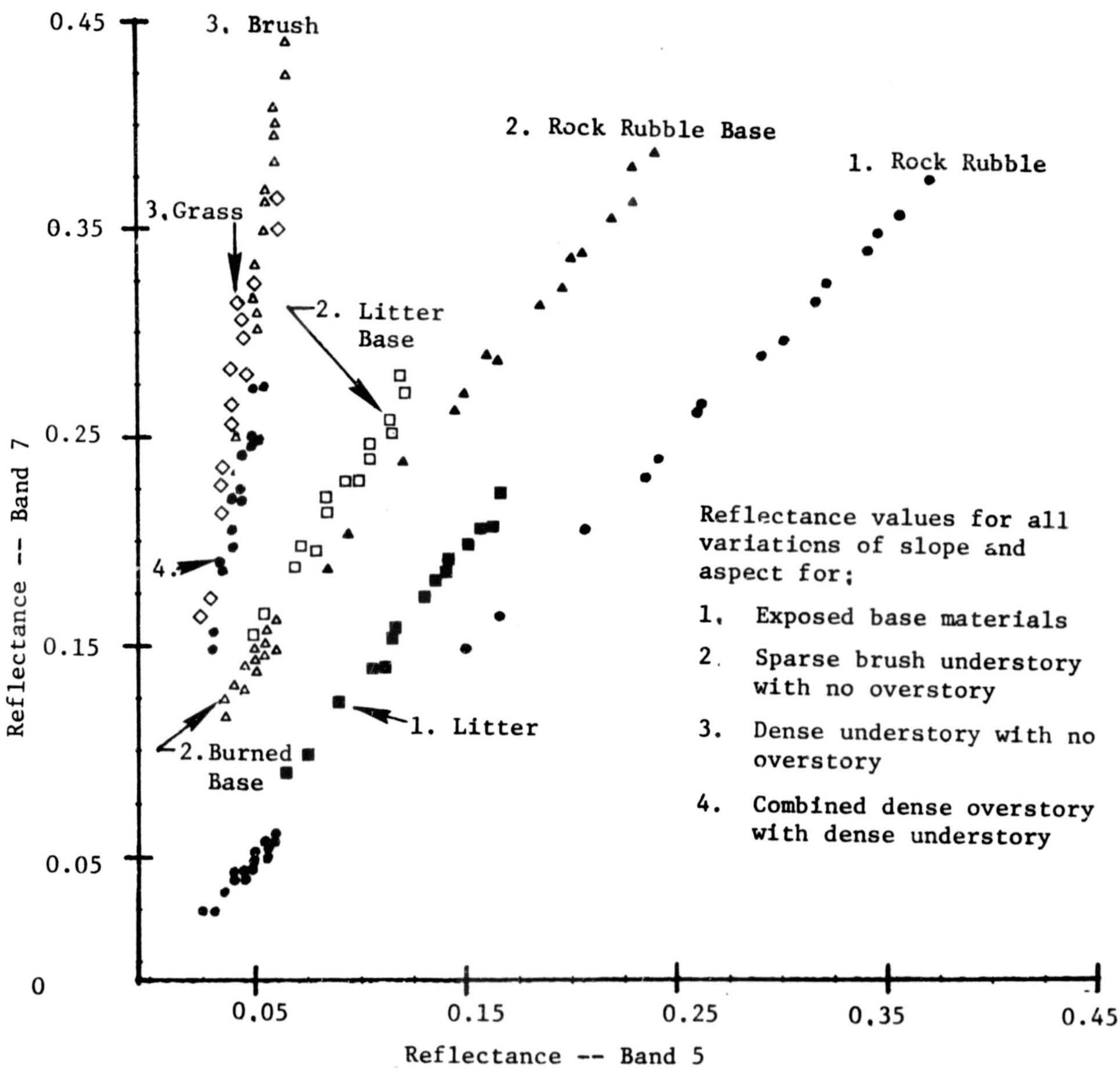


FIGURE 11. CANOPY REFLECTANCE FOR SEVERAL OVERSTORY/UNDERSTORY SITUATIONS PLACED ON ALL COMPUTED VARIATIONS OF TOPOGRAPHIC SLOPE AND ASPECT

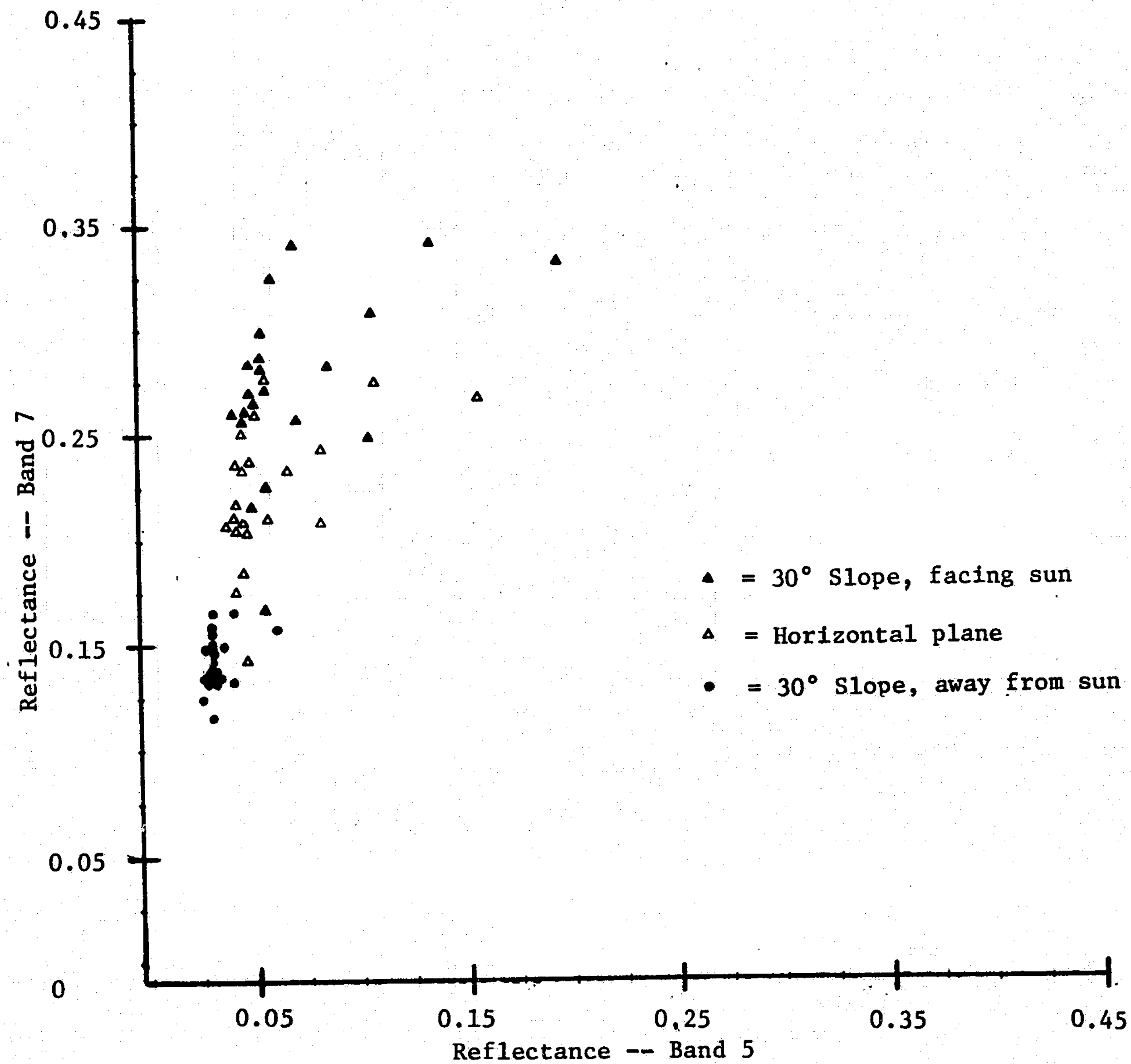


FIGURE 12. CANOPY REFLECTANCE FOR SITUATIONS OF SPARSE OVERSTORY PLACED ON SELECTED TOPOGRAPHIC VARIATIONS

3.3.3 DISCRIMINABILITY OF OVERSTORY/UNDERSTORY SITUATIONS

Figure 9 illustrates that increasing densities of tree overstory exert a dramatic effect on reducing the wide range of spectral variability from that noted for the completely exposed situations of simulated understory conditions. More importantly, reflectance values for situations of increased overstory density occur within the same spectral space defined by some of the exposed understories. Thus, it seems likely that various combinations of overstory and understory will be spectrally similar and perhaps undifferentiable from certain completely exposed understories.

To quantify the effect of varying tree density on the discriminability of understory conditions, we carried out a simulation of multispectral discrimination for the sparse, intermediate, and dense overstory situations. Model-computed Landsat reflectance values for all 21 understory conditions beneath each overstory density class were used to compute standard classifier signatures, each signature consisting of four mean values and covariance matrix. Only the reflectance values for horizontally oriented canopies were used for computing these signatures. The set of three signatures was then utilized to classify two sets of model-computed, four-channel reflectance values that represented, first, all horizontally oriented overstory/understory situations and, secondly, all other topographically varying canopies. The data were classified with a quadratic decision rule and classification rejection threshold corresponding to a 0.001 level of significance.

Figure 13 illustrates the three signatures that represent all variations of understories beneath sparse, intermediate, and dense tree overstory, respectively. (Negative values in Band 5 were not actually present; the ellipses extend across the y-axis as a result of the normality assumption and the actual distribution of data values.) The results of classifying all horizontally oriented overstory/understory situations are presented in Table 3(a). Classification performance is

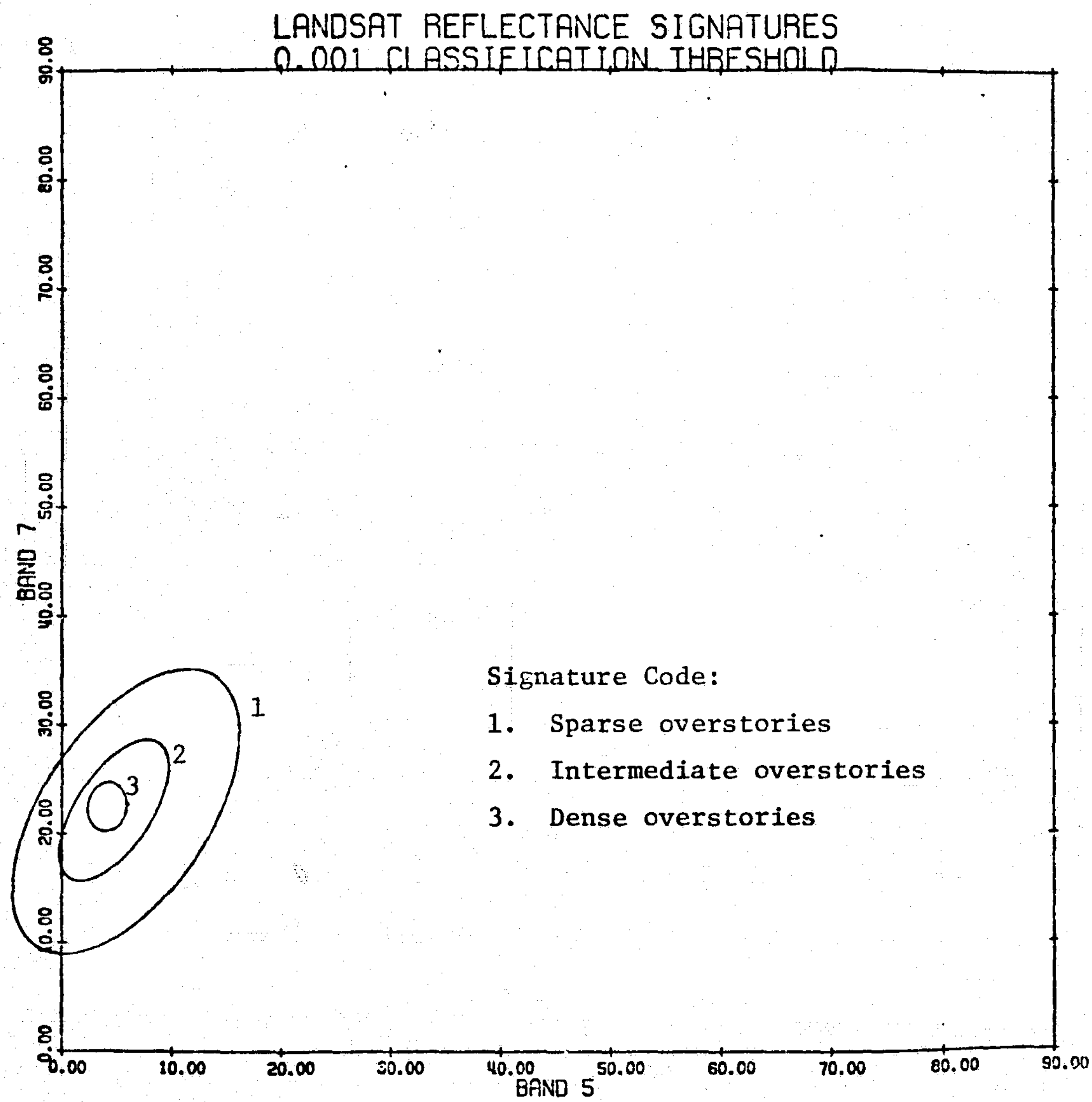


FIGURE 13. COMPUTED SIGNATURES FOR SPARSE, INTERMEDIATE, AND DENSE OVERSTORY SITUATIONS

highest for dense overstories where the common overstory conditions create a relatively unique spectral response that has only a slight probability of confusion with other less dense overstories or completely exposed understories. As tree density decreases, its dominance of the total canopy reflectance decreases, and the intermediate density canopies are more often confused with other canopy situations. The effect of sparse tree cover causes the greatest amount of confusion between sparse overstories and the intermediate overstory class and the exposed understories.

Table 3(b) shows a significant decrease in classification performance due to the influence of topography. The table suggests that the topographically influenced decrease in performance is most severe for dense overstories and progressively less so for intermediate and sparse overstories. An explanation is that a given terrain-induced shift in reflectance results in a greater change across the compact signature density function of the dense overstories than it does across the more dispersed density functions of the intermediate and sparse overstory situations.

TABLE 3. CLASSIFICATION RESULTS FOR MODEL-COMPUTED REFLECTANCE VALUES REPRESENTING SIMULATED OVERSTORY/UNDERSTORY SITUATIONS.

(a) HORIZONTALLY ORIENTED CANOPIES

Ground Truth	No. Data Points	Percent Classified as			
		Dense Forest	Interm. Forest	Sparse Forest	Unclass.
Dense overstory	21	90.5	9.5	0	0
Interm. overstory	21	9.5	81.0	9.5	0
Sparse overstory	21	0	38.1	61.9	0
No overstory	21	0	0	38.1	61.9

(b) ALL OTHER TOPOGRAPHIC VARIATIONS

Ground Truth	No. Data Points	Percent Classified as			
		Dense Forest	Interm. Forest	Sparse Forest	Unclass.
Dense Overstory	294	15.6	54.8	20.4	9.2
Interm. Overstory	294	3.1	59.5	35.7	1.7
Sparse Overstory	294	0	24.8	72.5	2.7
No Overstory	294	0	0	26.2	73.8

3.4. CONCLUSIONS AND RECOMMENDATIONS RELATED TO REFLECTANCE MODELING

As a result of simulating a number of forest canopy overstory, understory, and topographic variations, model-computed reflectance values were used to analyze the effects of various parameters on forest canopy reflectance.

3.4.1. CONCLUSIONS

The effects of vegetation density on overall canopy reflectance differed rather dramatically, depending on spectral band, base material, and vegetation type. For example, reflectance changes caused by variations in vegetation density were hardly apparant for a simulated burned surface in Landsat Band 5, while large changes occurred in Band 7. For Band 7, reflectance changes caused by varying densities of each type of vegetation were not always consistent in direction of change. In addition, the effect of base material caused wide variations in reflectance for common densities of vegetation in the sparse and intermediate density classes. For dense vegetation, reflectance differences among vegetation types were not apparant in Band 5, but did exist in Band 7.

When increasing densities of tree overstory were placed over understories, intermediate to dense overstories effectively masked the understories and dominated the spectral signatures. Only the situations of sparse overstory manifested changes in reflectance that appeared to offer any hope for distinguishing the presence of specific understory situations. Dramatic changes in reflectance occurred for canopies placed on a number of varying topographic positions. Such changes were seen to result in the spectral overlap of some non-forested with densely forested situations. Thus, it is important that topographic effects be taken into account if information extraction is to be maximized (see Reference 6 for a discussion of the joint use of topographic and Landsat data).

A quantification of the multispectral discrimination capabilities of signatures for sparse, intermediate, and dense forest overstory situations showed that the greatest amount of confusion in the classification results occurred in situations of sparse overstory. These sparse overstory situations had variability directly attributable to the different understory conditions that were only partially masked by the overstory. Topographic variations greatly reduced classification performance for the dense and intermediate overstory situations.

3.4.2. RECOMMENDATIONS

It is recommended that:

1. Field measurements be made and analyzed to validate and refine the reflectance modeling of coniferous forests that was initiated in this study.
2. Reflectance modeling activities be extended to deciduous forests, and
3. The model be increasingly employed in the investigation of issues relating to the capabilities and limitations of remote sensors for forest resource surveys.

4

THE POTENTIAL FOR INFERRING UNDERSTORY INFORMATION

By definition, forest overstories at least partially block direct viewing of understory vegetation by most remote sensors. Many forested regions contain canopies too dense to allow direct viewing of the understory to any appreciable extent. Therefore, it would be of interest to know if information about the canopy overstory, derived from remote sensors, and/or site-related information, obtained from non-remote sensing sources, can be used to infer information about the partially or completely masked understory.

To address this issue, pertinent published literature was reviewed and analyzed. Our approach treated two important aspects of understory information. First, relationships between the species composition of understories and the properties of overstories, as well as site factors, were considered. Secondly, the biomass production of understories was considered, relative to overstory properties and site factors. Both the composition and production of understories potentially impact management decisions regarding grazing (capacity and condition of range), forest fire control, and watershed management.

This section summarizes the findings of our investigation, with full details being presented in Appendix I. Our conclusion is that a combination of both ancillary site information and remote sensing-derived overstory properties is desirable for inferring understory composition and production. The role of remote sensing for providing overstory properties is limited in this discussion to the assessment of overstory density and species composition. Both of these capabilities have been the subject of a number of investigations. Various ranges of forest densities have been reported as successfully classified, while for species composition, deciduous vs. coniferous classifications have been quite accurate. Section 5 of this report investigates the use of fine-resolution MSS data for classifying individual types of forest canopy components, to include various kinds of overstory crowns. Such classification could provide more accurate estimates of overstory density and species composition.

Also, because of the nature of the inference treated in this discussion, we do not specifically address the role of remote sensing for providing direct inputs on understories that are visible through sparse overstories. Section 3 provides indications that some general species composition and variations in biomass production might be detectable beneath sparse overstories, while Section 5 demonstrates the potential for fine-resolution MSS data to directly sense understories.

4.1 UNDERSTORY SPECIES COMPOSITION

Relationships between the species composition of forest understories and various properties of forest overstories can be sufficiently variable that the accurate inference of understory species composition on the basis of remotely sensed overstory properties alone is unreliable. Circumstances no doubt can occur that will permit reliable overstory/understory associations--principally in stable communities where one or more site factors severely limits vegetation growth such that the diversity of species is exceedingly small. However, for most regions of temperate and tropical forest communities, the distributions of various overstory and understory species broadly overlap along environmental gradients according to their individual site requirements. In addition, species distributions vary on a time scale governed by the cyclical processes in stable communities and by the more dramatic successional trends of non-stable communities that result from natural and man-caused disturbances such as fire, logging, grazing, and control programs. As a result, vegetation communities are most often comprised of combinations of overstory and understory species populations that are spatially variable and not entirely consistent in their occurrence from place to place.

Site information may provide a better independent basis for inferring understory species composition. The generally more restricted ecological tolerance of many understory plant species limits their occurrence to sites of more specifically defined conditions than for overstory species. The existence of more or less consistent associations between many understory species and local site factors is supported by the frequent study of understory plant species as indicators of site quality. Once identified, factors of site that include topography, soil, biota, and climate could serve as the primary basis for inferring understory species composition.

It is likely that elements of overstory information, when combined with site information, could improve the accuracy of inferring understory composition. Such combination provides an additional elaboration of the specific site factors that collectively determine the species composition of the understory.

4.2 UNDERSTORY BIOMASS PRODUCTION

The documentation of generally consistent relationships between understory biomass production and overstory density for various forest cover types suggests that considerable potential exists for inferring understory production on the basis of overstory density The literature indicates that the inference of little or no understory production can be made for many situations of intermediate to dense overstories. For sparse overstory situations, a predetermined inverse relationship can enable inference of the potential for understory biomass production. In addition, sparse overstory situations enable the best opportunities for direct views of the understory. This is fortunate since areas conducive to high understory production are of great consequence to resource management decisions. The identification of overstory species composition by remote sensors may improve the inference of understory production potential as a function of overstory density. For example, the existence of coniferous vs. deciduous overstory may have a significant effect on understory production.

Although greatly influenced by overstory density, the potential for understory production is also dependent on the physical factors of the site and its past history. Local site factors such as soil type, insolation as determined by topographic position, and climatic conditions such as temperature and precipitation can cause the production of understory vegetation to vary greatly beneath uniformly sparse overstories. In addition, the past history of the site, including both natural and man-caused disturbances, can have profound influence on understory production.

4.3 RECOMMENDATION FOR COMBINED USE OF REMOTELY SENSED AND ANCILLARY INFORMATION

The previous discussion makes clear the fact that neither remote sensing nor ancillary information by itself will permit the best possible inference of understory conditions. Both site information derived from ancillary sources and overstory properties provided by remote sensors are desirable. The combination of both types of information into a common data base could provide a means for increasing the amount of information about forest understories that is available for making resource management decisions.

Site factors are fairly constant parameters that, even though acquired by methods less efficient than remote sensing, do not require repeated update. Such factors can include topographic, soil, biotic, and climatic conditions. Once acquired, they are amenable to storage in a computerized data base as point-source or area-wide information [6].

Remote sensors can supply data in a format readily compatible with computer-stored site information. More importantly, the data are efficiently collected, making them most appropriate for repeatedly monitoring any temporally variable overstory properties that can contribute to the inference of understory conditions. Thus, periodic update of overstory density in immature or recently thinned timber stands could potentially provide improved estimates of grazing capacity and range condition. Similarly, updated information provided by remote sensors on disturbances within overstories caused by fire, wind, disease, and insects would permit reassessment of understory conditions that might impact grazing potential, fire danger ratings, and watershed capabilities.

We suggest that the potential for inferring understory information will be best realized when the capability for efficient joint storage and utilization of data obtained from remote sensors and other ancillary sources is developed.

5
EMPIRICAL ANALYSIS OF SPECTRAL COMPONENTS WITHIN FOREST CANOPIES

The modeling analysis of Section 3 dealt, in effect, with coarse-resolution aspects of the remote sensing of forest scenes. Here in Section 5, we turn to fine-resolution aspects. A previous study [11] was conducted by this organization, using aircraft MSS data having a fine spatial resolution -- $(2 \text{ meters})^2$. An additional study was conducted as a part of this contract to investigate two technical issues which were not resolved in the prior study. This added study is fully described and documented in Reference 12. In addition, we analyzed signatures extracted from individual forest canopy components within that data set, and the results are presented below.

It was found in Reference 12 that, when the fine-resolution data were used in a conventional fashion to compute signatures representative of forest stands, excessively large variances resulted. These large signature variances were caused by the wide range of signal variation within any given forest stand that resulted from individual resolution elements falling entirely within various forest canopy components such as illuminated crowns of overstory tree species, illuminated and shadowed understory, etc. The use of several such signatures, in the application of a conventional computer classification technique to fine resolution data, resulted in poor classification of forest stands. The poor results were attributed to the large, overlapping variances of the signatures. The great overlap of signature distributions was primarily caused by the fact that many canopy components within different stands had similar spectral properties.

In spite of the above results, our belief was that the fine resolution data had unused potential for classifying forest stands. Therefore, we studied the utility of fine-resolution MSS data for discriminating specific components of forest stands that may in themselves be of interest to a forest manager. A new procedure for classifying the data, based on the proportions of components in each stand, was then shown to provide substantially improved forest stand classification accuracy. The details of the study are described in the remainder of this section.

5.1 ANALYSIS OF CANOPY COMPONENT DISCRIMINABILITY

5.1.1 DATA AND TEST SITE DESCRIPTION

Airborne MSS data utilized for this study were collected on 20 Nov 74 (Mission 290) from an altitude of 610 meters (2000 feet) over the Sam Houston National Forest in Eastern Texas. The data had an inherent spatial resolution of $(2 \text{ meters})^2$ and included 11 spectral channels (Table 4). This data set had been previously analyzed in a study of forest classification accuracy for successively coarsened cases of MSS spatial resolution [11-13] and, consequently, was readily available for the current canopy component analysis.

TABLE 4. SPECTRAL COVERAGE PROVIDED BY THE MSS DATA OF MISSION 290

Sensor Channel	Spectral Band Limits (μm) at 50% Response Points
1	0.41 - 0.44
2	0.45 - 0.49
3	0.49 - 0.54
4	0.53 - 0.57
5	0.57 - 0.61
6	0.61 - 0.65
7	0.65 - 0.69
8	0.69 - 0.73
9	0.76 - 0.86
10	0.95 - 1.03
11	8 - 12

The data provided ground coverage of approximately 2 km along the flightline and 1.5 km swath width. To exclude sources of spectral variation that might result from large scanner view angles (i.e., large changes in atmospheric path length and bidirectional reflectance effects), the outside edges of the total scanner field of view were excluded such that only the region of data located within $\sim 25^{\circ}$ either side of the flightline nadir was utilized. Thus, a near-vertical view of the forest canopy was provided which limited ground coverage to about 0.75 km swath width. Nonetheless, such coverage included approximately 500,000 resolution elements.

Forest features within the area covered by the data included stands of Loblolly pine and Shortleaf pine. Existing USFS timber stand and compartment boundary maps enabled subdividing cover types into condition classes on the basis of age and size of the majority of trees in the stand. Figure 14 illustrates the location and appearance of the five analyzed forest stands within the test site. Stand numbers are identified in Table 5.

3.1.2 SIGNATURE EXTRACTION

The analysis of canopy component discriminability was carried out with signatures that represented specific spectral classes of components within each of the five forest stands. To aid the selection of resolution elements for signature computation, a single channel of MSS data was level-sliced and printed in a color-coded digital map format and subsequently superimposed with 1:4000 scale CIR photographs by using a Bausch and Lomb Zoom Transfer Scope. Individual elements were selected that corresponded to each spectral class of components in the canopy that were evident on the large-scale photography. Within each stand area, approximately 100 elements were selected and used to compute a signature (mean vector and variance/covariance matrix) for each spectral class of components. A total of 24 such component signatures were computed in all from the five forest stands in the data.

FIGURE 14. FOREST STANDS IN MSS DATA, SAM HOUSTON NATIONAL FOREST

TABLE 5. FOREST STANDS ANALYZED

Forest Stands		Stand No.
Shortleaf Pine	Immature	1
	Mature	2
Loblolly Pine	Immature	3
	Mature	4
Pine Regeneration		5

Table 6 identifies all component signatures that were computed from each forest stand. The major spectral classes of forest canopy components that were identified included three types of illuminated crowns (pines, hardwoods, and leafless), shadowed crowns, and conditions of illuminated and shadowed understory. Among both the illuminated pine crowns and illuminated hardwood crowns, two distinctive subclasses were identified to span the spectral variability present. Because of the low sun elevation angle (40°) that existed at the time the data were collected, much of the background material within each feature (shrub and herbaceous vegetation, litter, etc.) was shadowed by trees. Thus, a signature for illuminated understory could be extracted only from the area of pine regeneration in which small trees (saplings) were spaced far enough apart to permit substantial background exposure.

Figure 15 displays the spectral characteristics of the signatures from one of the five stands, in the two of eleven available scanner channels which were best for discriminating between the canopy components. This figure readily points out the wide spectral complexity that can exist, not only among various trees within the canopy overstory, but also between the overstory and the understory. Additionally, the effect of shadows cast onto the understory serves to introduce a greatly different class of spectral component within the canopy.

5.1.3 PRINCIPAL COMPONENT AND SIGNATURE GROUPING PROCEDURES

The discriminability of all twenty-four 11-channel signatures was examined by performing a principal components* analysis. Figure 16 illustrates the locations of signature means for the first two principal components. The near proximity of signature means within each circle suggests little capability for reliably discriminating between similar types of component spectral classes from stand to stand.

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*A principal component is a linear combination of values in the 11 data channels; elsewhere in this report, components are canopy components as defined in Table 6.

TABLE 6. COMPONENT SIGNATURES EXTRACTED FROM FOREST STANDS WITHIN THE SAM HOUSTON NATIONAL FOREST

Stand No.	Feature	Component Signatures							
		ICP 1 (1)	ICP 2 (2)	ICH 1 (3)	ICH 2 (4)	ICTL (5)	SCP (6)	SU (7)	IU (8)
1	Pine Regeneration	✓	✓	✓	✓	✓(9)		✓	✓
2	Immature Loblolly Pine	✓	✓	✓				✓	
3	Mature Loblolly Pine	✓	✓	✓			✓	✓	
4	Immature Shortleaf Pine	✓	✓	✓				✓	
5	Mature Shortleaf Pine	✓	✓	✓		✓(9)		✓	

---

(1) ICP 1: Illuminated crowns of pine trees (Spectral Class I)-- green conifer foliage that appears red on CIR (color infrared) photography.

(2) ICP 2: Illuminated crowns of pine trees (Spectral Class II)-- somewhat less green conifer foliage that appears pink on CIR photography.

(3) ICH 1: Illuminated crowns of hardwood trees (Spectral Class I) -- yellowish to light brown hardwood foliage that appears generally whitish on CIR photography.

(4) ICH 2: Illuminated crowns of hardwoods (Spectral Class II) -- reddish hardwood foliage that appears yellow on CIR photography.

(5) ICTL: Illuminated crowns of trees that are leafless (possibly leafless hardwoods or dead pines).

(6) SCP: Shadowed crowns of pine trees. These crowns were large enough to locate resolution elements on an aspect facing away from the sun.

(7) SU: Shadowed understory.

(8) IU: Illuminated understory.

(9) Elements from two feature areas were combined to compute a single signature.

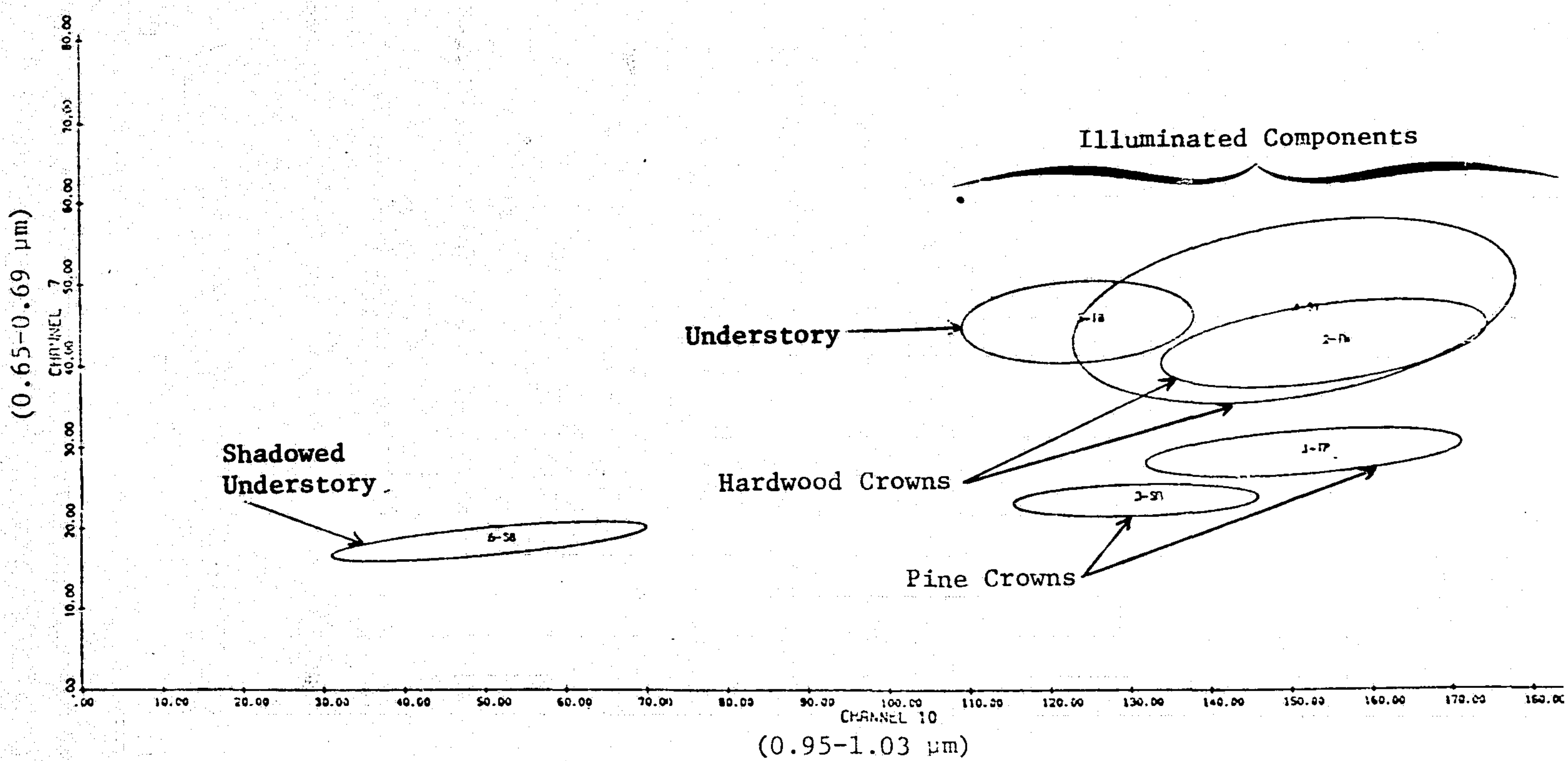


FIGURE 15. FOREST CANOPY COMPONENT SIGNATURES EXTRACTED FROM THE STAND OF PINE REGENERATION (Stand No. 5)

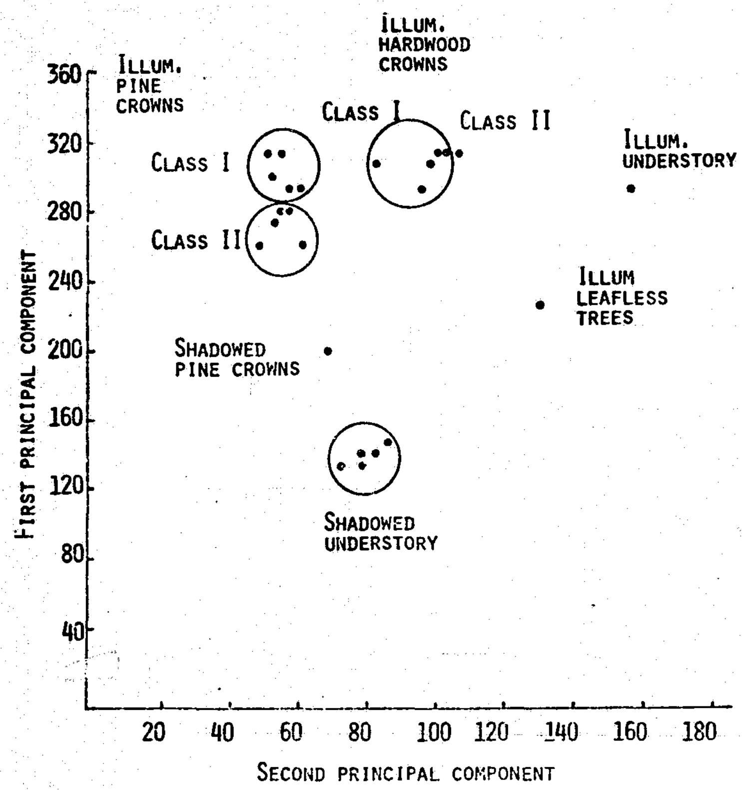
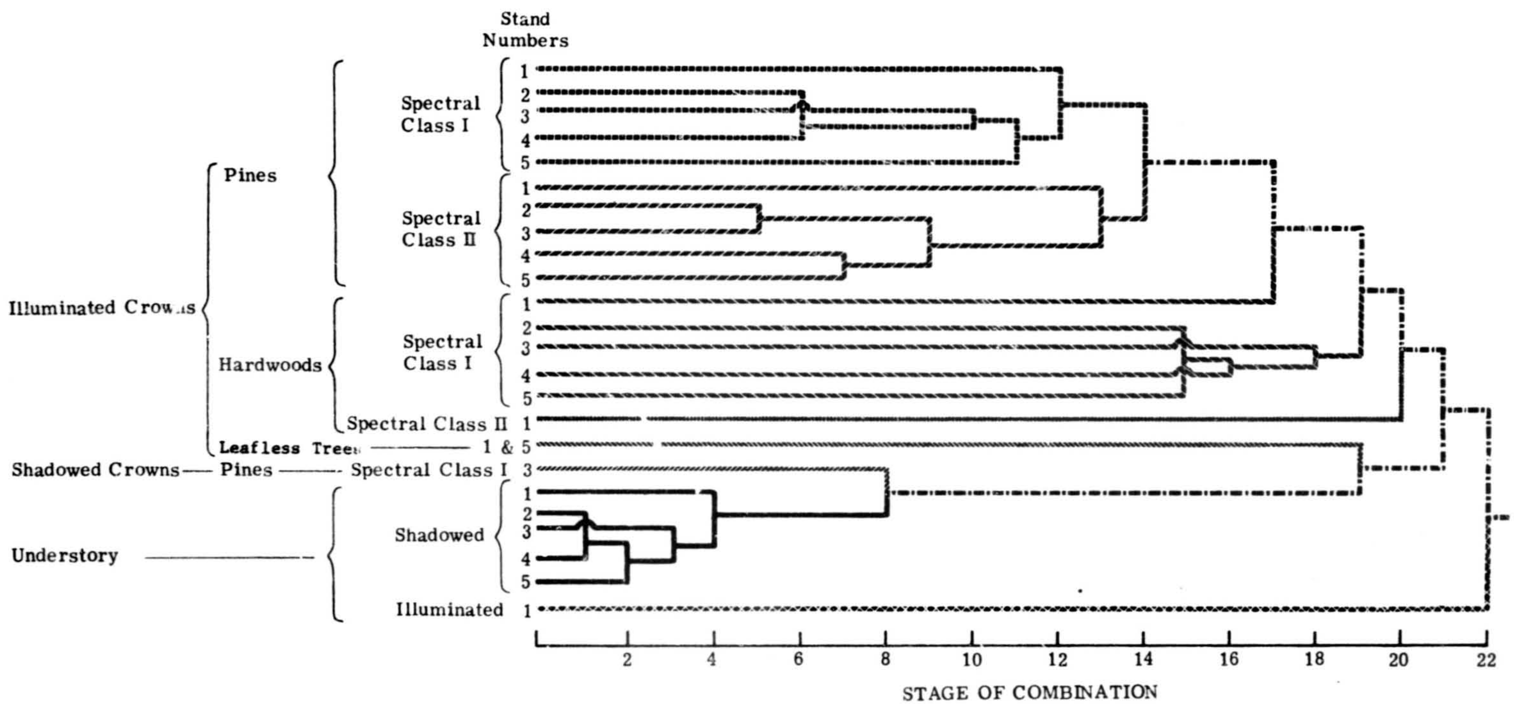


FIGURE 16. SCATTER PLOT OF CANOPY COMPONENT SIGNATURE MEANS IN PRINCIPAL COMPONENT SPACE

In other words, spectral similarities among shadowed understories and among illuminated tree crowns within similar spectral classes from stand to stand were sufficiently great to make their unique classification very uncertain. Therefore, we combined the set of 24 signatures into a smaller number of more discriminable signatures. A computer program was used which determines the most similar pair of signatures, combines them, and then, on successive steps, groups and combines the most similar pair of the remaining individual and combined signatures. The measure used for deciding which signatures to combine was average ranking according to three criteria based on the 11-channel signature statistics -- namely resultant combined determinant, resultant combined trace, and between-signature Bhattacharyya distance.

Figure 17 presents a diagram that indicates the manner in which the 24 signatures were successively grouped. Note that individual component signatures (with one exception) were combined with others of the same spectral class prior to subsequent combination. This confirmed the previously noted observation that any given type of canopy spectral component signature matched the same type in the other four forest stands more closely than it matched different component signatures within its own stand. For example, the complete groupings of all shadowed understory signatures at early stages of combination indicated a very large amount of spectral similarity among signatures of shadowed understory regardless of the stand.

The signature combining computer program was allowed to run until all the different spectral classes were subsequently grouped and only a single composite 11-channel distribution remained. The sequence by which different spectral classes of components were grouped provides for some noteworthy observations. First, the early combination of the shadowed crown and shadowed understory spectral classes seems to attest to the significant effect of shadows cast onto tree crowns for reducing the discriminability of such crowns from shadowed portions of the canopy



Key:

Stand 1 = Pine Regeneration
Stand 2 = Immature Loblolly Pine
Stand 3 = Mature Loblolly Pine
Stand 4 = Immature Shortleaf Pine
Stand 5 = Mature Shortleaf Pine

FIGURE 17. DIAGRAM ILLUSTRATING THE PROGRESSIVE PAIRWISE COMBINATION OF FOREST CANOPY COMPONENT SIGNATURES FROM FIVE FOREST STANDS

understory. Secondly, despite the natural spectral variations among illuminated crowns, pines were distinguishable from hardwoods and from leafless trees. Note, however, that all illuminated spectral classes of overstory vegetation are grouped together prior to combination with shadowed spectral classes -- again illustrating the dramatic effect of shadowed regions within the canopy. (The signature for illuminated leafless trees probably was influenced by the spectral properties of shadows since individual resolution elements selected to compute this signature most certainly included portions of shadowed understory. Thus, the combination of this signature with other shadowed spectral classes is not considered to be a significant contradiction of the prior statement.) Finally, illuminated understory is the last spectral class to be grouped, suggesting that the greatest dissimilarity in spectral properties existed between illuminated portions of the understory and all other canopy components.

5.1.4 TESTS OF CANOPY COMPONENT CLASSIFICATION

A set of combined signatures representing the eight different spectral classes of canopy components was finally used to determine the capability for classifying various components of a forest canopy. Two classification tests were implemented -- one through simulation and the other through empirical data processing.

The first test utilized a computer program to simulate the classification performance among the signatures. For each signature taken in turn, 1000 data values were generated at random from a multivariate normal distribution according to the signature's specified multichannel mean values and covariance matrix and then classified either as belonging to one of the eight types of canopy components or as being sufficiently different from all to remain unclassified. The fractions of data values assigned to each component signature provided estimates of the probabilities that data values representative of one type of canopy component would be correctly classified, misclassified as another component, or remain unclassified. The classification algorithm and decision boundaries were dictated by the optimized pairwise linear decision rule that is often employed at ERIM for classifying multi-spectral data [14].

The second test of classification performance was determined by classifying the entire set of individual resolution elements previously selected for the computation of all 24 signatures from the five forest stand areas.

Results of the two tests appear in Table 7. The simulation results represent an ideal performance level to be expected under the assumption of multivariate normality for all data values classified by the signatures. Departures of the results of the empirical test from the simulated results would be attributable to non-normal distributions of the real data values that were classified in all five stand areas. Table 7 illustrates that relatively high classification performances were achieved, with good agreement between simulated and empirical results. When the empirical results were averaged over canopy components, classification accuracy exceeded 80 percent and surpassed 90 percent when the two spectral classes within each of the pine and hardwoods crown categories were combined.

Although the empirical results of Table 7 are representative of training data, they nevertheless provide an upper bound of component classification performance to be expected if further classification of completely independent test elements were accomplished. The scope of this study did not allow for the major expenditure of effort that a selection of individual test elements would have involved. Thus, these results are intended to be indicative of the potential for classifying canopy components with these data on the assumption that the signatures are representative of their respective component spectral classes. Additional testing of this capability is recommended.

TABLE 7. CLASSIFICATION PERFORMANCE FOR EIGHT CANOPY COMPONENT SPECTRAL CLASSES

Component Spectral Class		Simulated Performance for Signatures (Percent Correct)		Actual Classification of Resolution Elements in All 5 Stand Areas (Percent Correct)	
Illuminated Pine Crowns	Class I	77.2	93.2	72.9	90.8
	Class II	84.5		84.5	
Illuminated Hardwood Crowns	Class I	86.5	96.1	86.9	92.3
	Class II	76.9		70.0	
Illuminated Leafless Trees		93.9		95.3	
Shadowed Pine Crowns		84.4		87.1	
Shadowed Understory		96.4		96.2	
Illuminated Understory		93.9		90.4	

5.2 USE OF CANOPY COMPONENT INFORMATION IN PROPORTION-SPACE CLASSIFICATION OF FOREST STANDS

The relatively high classification performance achieved for the canopy component signatures provided evidence that spectral components could be reliably mapped within forest stands with fine-resolution MSS data. To investigate the utility for doing so, we classified regions of contiguous data within each forest stand area. With one exception, each such region of data contained 12,500 resolution elements (100 lines x 125 elements). Because of the limited sized area for Stand 3, the region within this stand contained only 6500 resolution elements (100 lines x 65 elements). The data were classified using the ERIM linear decision rule and all 11 spectral channels. Figure 18 illustrates the proportions of resolution elements classified in each such data region. Note that two separate data regions were classified within pine regeneration in order to observe the extremes of tree density that existed within the feature.

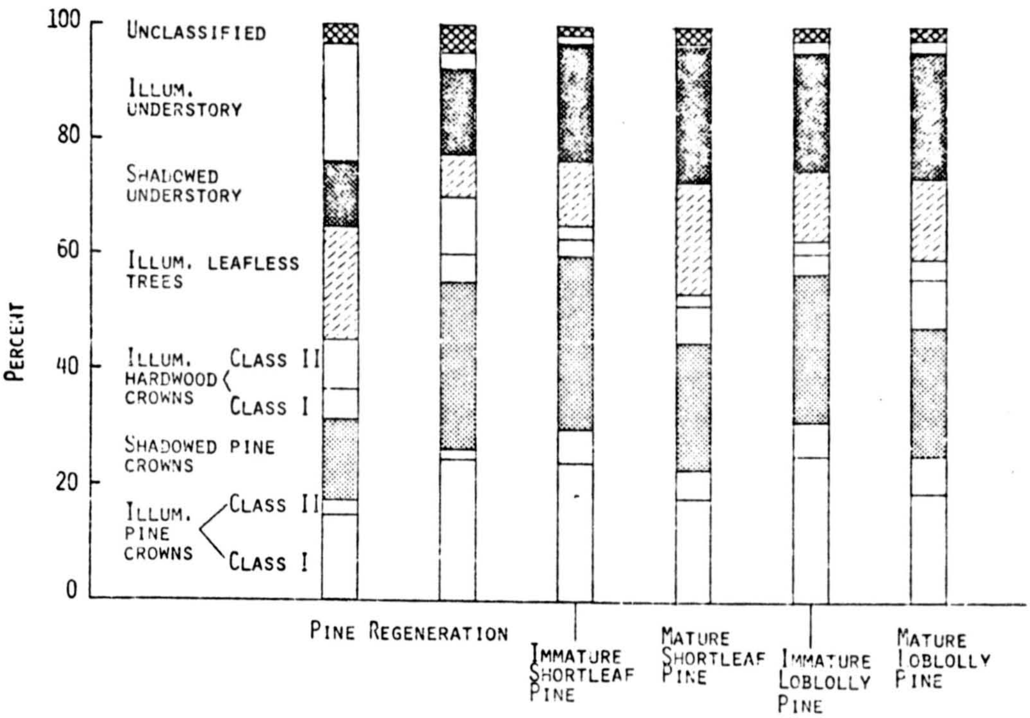


FIGURE 18. PROPORTIONS OF CANOPY COMPONENTS FOR CONTIGUOUS DATA REGIONS WITHIN EACH FOREST STAND

Differences in proportions of classified components from stand to stand, such as manifested in Figure 18, had been anticipated. Furthermore, it seemed possible that the proportions of components within each stand could provide a means for discriminating among stands. To test this hypothesis, we created a new data set by partitioning the data region within each stand into cells of 1000 $(2m)^2$ resolution elements (each cell measuring 50M by 80M ground coverage). For each cell, we established a new data vector giving the proportions of previously classified canopy components. Thus, a new "proportion space" was defined for describing the cells. These data vectors were then averaged together to compute signatures for component proportions in each stand.

Finally, we determined forest stand classification performance using the proportion signatures.

First through simulation, classification performance was determined by generating data values at random according to each proportion signature's specified multivariate normal distribution and classifying these values (See Section 5.1.4). Classification performance was then also determined empirically by classifying each 1000-element cell in the actual data set. The results of these determinations indicate the potential for accurately classifying real data using the proportion-space technique.

Figure 19 provides the overall (averaged over 5 stands) performances achieved for the simulated and empirical tests of forest stand classification using the proportion-space technique. To illustrate the dramatic improvement over results with a conventional data classification technique, these results are compared to the classification performances previously achieved on the (2 meter)^2 data over the same regions of data [12]. The classification performance provided by the proportion-space technique also surpassed the improved classification performances

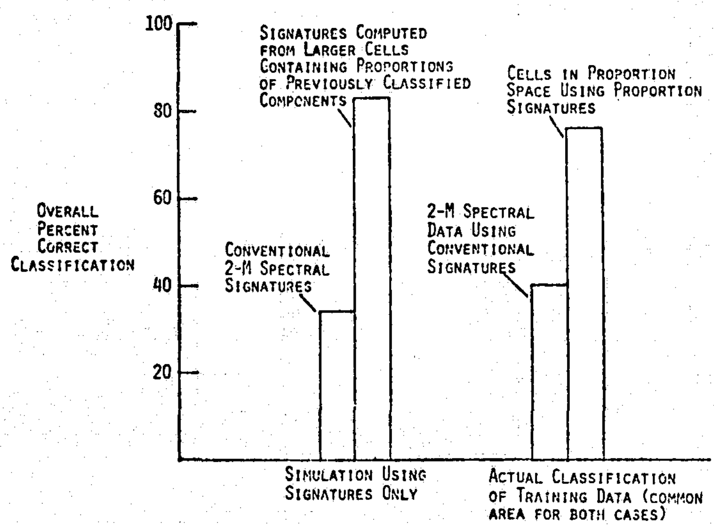


FIGURE 19. COMPARISON OF PROPORTION-SPACE AND CONVENTIONAL CLASSIFICATION PERFORMANCES FOR ALL FOREST STANDS

previously achieved when the conventional data classification techniques were applied to several cases of coarsened spatial resolution (data having elements as coarse as $(64m)^2$)[12].

5.3 CONCLUSIONS AND RECOMMENDATIONS REGARDING THE EMPIRICAL ANALYSIS OF FOREST CANOPY COMPONENTS

The following conclusions and recommendations are based on our analysis and processing of fine-resolution $(2m)^2$ MSS data acquired over five forest stands in Eastern Texas.

5.3.1 CONCLUSIONS

A total of 24 signatures, computed for individual spectral components in the fine-resolution MSS data, illustrated the wide complexity of spectral detail that exists within typical forest canopies. Spectral variations were caused chiefly by the existence of different types of tree crowns, the contrast between the understory and overstory components, and, very significantly, the occurrence of shadows within the canopies.

Analysis of the signatures indicated that canopy components can exhibit very similar spectral properties from stand to stand -- thus explaining the significant overlap that can occur among the multivariate distributions of forest stand signatures computed in a conventional fashion from fine-resolution data.

An aggregated set of eight signatures, each representing a different spectral class of components common to all stand areas, exhibited a good capability for classifying the major components of forest canopies in this data set. Overall classification accuracy for resolution elements of canopy components that had been selected for signature computation exceeded 80 percent for the set of eight spectral classes and surpassed 90 percent when the two spectral classes within each of the pine and hardwoods categories were combined. The capability to classify the components of forest canopies could assist in providing the necessary information to support intensive forest management efforts. For example, tallying the proportions of classified tree crown components would enable crown closure to be determined for each of several tree crown spectral classes that may provide input into management decision affecting silvicultural or pest control operations.

Finally, by making use of the proportions of all classified canopy components, we devised a new proportion-space technique for classifying forest stands at a more general level of detail. Prior studies [12] showed increasingly accurate classification of forest stands when conventional techniques were employed on data of increasingly coarse spatial resolution; overall performance was worst (40.5%) for the finest resolution. In contrast, through use of the specialized proportion-space classification technique, data of a fine resolution that is useful for identifying canopy components were processed to obtain markedly improved (76%) overall forest stand discrimination. Such capabilities could be advantageous in multistage sampling surveys of forestry and rangeland resources.

5.3.2 RECOMMENDATIONS

The following recommendations are offered relative to the empirical multispectral analysis of forest canopy components in fine-resolution data.

1. The limited scope of this study and limited size of the (2 meters)^2 MSS data set has prevented rigid testing of the demonstrated technique for classifying component elements of forest stands. Because of the current USFS interests in detailed forest stand information, additional development and testing of this approach for providing detailed stand information seems warranted.

2. As an example of additional development of the approach, we recommend investigating more efficient and objective methods for defining signatures of forest canopy components. Possible approaches include spectral and spectral/spatial clustering techniques (See Volume II of this report [6]).

3. For this approach to the classification of forest stand component elements, the use of passive (terrain reflected solar energy) MSS data collected under high sun elevations would provide data having smaller proportions of object-cast shadows and thus better enable the assessment of forest understory components. We note that the use of an active (laser) scanner of the type developed by ERIM [15] would provide for the complete removal of shadows, thus offering the best opportunity for viewing the understory. The potential of such systems to provide desired information should be assessed.

4. Although not a subject of this investigation, we wish to note that imaging radar sensors do exist, including a dual-band dual-polarization (four-channel) synthetic-aperture radar [16], which offer a promising but largely unassessed potential for forestry and rangeland applications. This potential also should be evaluated in the future.

5. Finally, the promising results achieved for overall forest stand discrimination using the proportion-space classification technique demonstrates the potential capability of fine-resolution MSS data to provide both detailed and general levels of information. We recommend additional development of this capability, particularly as it might be employed in a multistage sampling survey of forested regions.

APPENDIX I

THE POTENTIAL FOR INFERRING UNDERSTORY INFORMATION

By definition, the existence of forest overstories serves at least to partially block direct viewing of understory vegetation by most remote sensors. Many forested regions contain canopies too dense to allow direct viewing of the understory at all. Therefore, it would be of interest to know if information about the partially or completely masked understory can be derived from remotely sensed information about the canopy overstory and/or from site-related information. To address this issue, we have reviewed pertinent published literature with the objective of determining the ability to infer information about forest understories from knowledge of the canopy overstory and site information. Our approach has treated two important aspects of understory information. First, we considered the bases for associating the species composition of understories with properties of overstories and site factors. Secondly, we considered the biomass production of understories, relative to overstory properties and site factors.

I.1 UNDERSTORY SPECIES COMPOSITION RELATIONSHIPS TO OVERSTORY AND SITE INFORMATION

This section first summarizes the ecological bases for the species composition of vegetation communities. The evidence indicates little basis for the reliable inference of understory species composition from knowledge of the forest overstory alone. Alternatively, the use of ancillary site information is suggested as a better basis for the inference of understory composition. This basis for inference might benefit from the addition of overstory density information provided by remote sensors as well as past site history.

I.1.1 ECOLOGICAL BASES FOR THE SPECIES COMPOSITION OF VEGETATION COMMUNITIES

A vegetation community is defined as a functional system of interacting, niche-differentiated species. Each such community is an expression at a point in time of the interaction and organization of its component species in concert with the environment. Accurate inference of understory species composition beneath partially or completely closed forest canopies would require more or less static associations of component species among vegetation communities. Certain minor species would have evolved toward close association with the dominants and exhibit a preferred co-existence. In addition, competing species would exclude each other at sharp boundaries along environmental gradients. Thus, characteristic assemblages of species having parallel distributions would occur in distinct zones in response to environmental factors. Finally, sufficient study would have had to produce acceptable definitions and descriptions of such communities.

In the broadest context, vegetation communities can be defined and described in terms of the structure or physiognomy of dominant life-forms and the major environmental factors to which the physiognomy is a response. Thus, the term formation is used to refer to broad groupings of vegetation such as temperate deciduous forest, boreal coniferous forest, temperate grassland, arctic tundra, etc. Quite excellent correlations have been derived for the distribution of formations and macro-patterns of temperature, precipitation, and evaporation -- evidence contributing to the prevailing opinion that formation distribution is primarily controlled by climate [17]. It is not surprising, therefore, that the distribution of formations frequently corresponds to latitude and elevation changes.

Typically, the species composition of the dominant life-forms varies throughout the geographic range of a formation. For example, the deciduous forest formation is comprised of several overstory species groups that include beech-maple and oak-hickory on upland sites and numerous other species groups on bottomland sites. Obviously, such variation in the distribution of dominant species is due to other factors of environment at work within the broad climatic range of each formation. Thus, more specific contexts of vegetation communities require consideration of all factors of environment which collectively make up the complex referred to as site.

Although capable of fairly precise definition at a given location, site conditions vary continuously (sometimes abruptly) in response to the topographic, soil, and biotic influences of the landscape and the interdependent micro-climatic variations that result [18]. The variation of each environmental factor through space constitutes an environmental gradient. Such gradients can be complex when they involve several environmental factors, i.e., changes in air temperature and soil moisture with distance up a mountain slope. As already stated, changes in the species composition of dominant life-forms are determined by environmental gradients. The basis for inferring understory species composition beneath forest canopy overstories will depend on how the entire species population of vegetation communities respond to environmental gradients.

Unfortunately, the issue of community species composition in response to environmental gradients has been clouded by an important controversy over the more fundamental question regarding the nature of the community. Two widely differing concepts of community structure have developed over this question. These concepts are typically referred to as the "organismic" view and "individualistic" view.

The organismic concept holds that the community is a complex organic entity that behaves as a unit in its relation to other communities, response to climate, local and geographic distribution, and in its evolution [19]. Field studies reveal that certain groups of species reach their optimum in the same community and, further, note that species of one such grouping never occur as important members of another group [17]. The assumption made is that natural communities exist as "fundamental units" of the landscape with discrete boundaries. Ecologists of the organismic "school" have, therefore, concentrated on discovering such units and classifying them in a hierarchical fashion.

The individualistic concept recognizes no intrinsic interrelation between species in respect to distribution or evolution. The community is a chance combination of species that occur together because of similarity in their environmental relations [19]. Studies of community variation have adopted approaches that are variously expressed as the continuum concept [20], gradient analysis [21], or ordination [22]. Although differing in their methods of assessment, these approaches all imply that within broad vegetational areas, changes in species composition will occur along environmental gradients without sharp lines of demarcation. Whittaker [23], using gradient analysis, shows that populations of species on study sites in Oregon and Arizona have scattered positions along topographic moisture gradients and broadly overlapping, bell-shaped distributions. He explains that competition between species tends to be reduced by the process of natural selection. Two species in close competition within the same range of environmental gradient will diverge along the gradient toward regions more conducive to the genetic and physiological requirements of the population majority. In other words, species adapt and evolve toward a difference of habitat requirements that is away from formations of groups of species with parallel distributions. Such evolution is rather toward a continuum of species populations along environmental gradients.

More and more available information supports the individualistic concept of the community -- that species populations are spatially continuous and that species groups are not entirely consistent from place to place [24]. Studies of forest communities have shown that individual species have different physiological and genetic tolerances to environmental gradients and, therefore, may exist in several different communities. Although some trees occur on specific sites, most trees have a wide ecological tolerance in that they may occur and prosper on a wide variety of sites. On the other hand, understory plant species in many cases have a more restricted ecological tolerance, being limited to more specific sites. Frequently such species are apt to be influenced further by the composition and density of the overstory [18].

The frequent study of understory plant species as indicators of site quality provides much documentation which supports the variability of understory beneath overstory. The classic Cajander system for site types in Finland [25] provides site index curves for both pure and mixed stands of spruce, pine, and birch. The quality of the site varied greatly as a function of the predominant understory species, each of which occurred under all overstories [18].

The classification of forest communities as habitat types frequently recognizes several understories in combination with a single type of overstory. For instance, the Ponderosa pine type in eastern Washington and northern Idaho has been subdivided into six associations according to whether the undergrowth is characterized by any of three species of grasses on stony, coarse-textured soils or three species of shrubs on heavier-textured, more fertile soils [26]. Similarly, in the central and southern Rocky Mountains, Alexander [27] provides many examples of habitat studies from isolated areas that show great diversity in the dominant types of understory vegetation that occur beneath spruce-fir, lodgepole pine, and quaking aspen forest cover types. Changes in understory vegetation are reportedly frequently influenced by local situations of altitude and aspect.

These findings by many investigators indicate little basis to allow for the reliable inference of understory species composition from knowledge of the forest canopy overstory alone. However, the frequently noted dependence of understory species occurrence on various site factors suggests that consideration of such factors may provide a better capability for inferring understory composition.

Any capability for inferring understory composition will also be dependent on temporal effects since community species composition varies with time. Goldsmith and Harrison [28] categorize the dynamic nature of vegetation with time into cyclical changes and directional changes. Cyclical changes occur on a relatively short time-scale and generally maintain the status-quo of the community over a long period. However, the distribution of species at times within the cycle can be affected. Seasonal changes represent an obvious occurrence that can influence the spatial pattern of annual vegetation. Less obvious are temporal changes in the distribution of individual species affected by competition within otherwise stable communities. Watt [29] related changes in the relative distribution of two species in a heathland community to the competitive ability of a species and its age. He noted that the competitive ability of a species was most aggressive when the majority of its population was in the building and mature growth phases of development. The species was least competitive when in the pioneer and degenerative phases of growth.

Many communities have been reported to exhibit these cyclical patterns of growth, and Goldsmith and Harrison [28] cite references for studies in grassland, woodland, tundra, and bog communities. While most cyclical patterns of growth are related to the life-history of individual species, some examples suggest that environmental factors such as fire, wind, frost-action, and fluctuating water-tables can accentuate certain phases of the cycle. In this respect they conclude:

> "...the pattern of vegetation may be a product of intrinsic change wrought by the plants themselves, may be caused by external environmental factors, or produced by a combination

of both. The implications of these cyclical processes for the community ecologist are that in certain circumstances spatial changes are largely the result of temporal changes and not due to initial differences in the habitat conditions."

Directional changes operate over a long time-scale and constitute the process of plant succession in which plant communities are successively replaced by others of different structure and species composition. Although distinct stages are recognized for convenience, the process is a continuous one. "Species populations rise and fall and replace one another along the time gradient in a manner much like that in stable communities along environmental gradients," [23]. Thus, it is possible that understories on similar sites could differ due to a difference in successional status.

Man-caused disturbances can produce changes in vegetation species composition that may be cyclical or successional in character, depending on the severity of the disturbance. Heavy grazing by livestock can alter understory species composition for reasons that include greater palatability of some species over others and soil compaction. Programs to control or eradicate some species (e.g., ribes for the control of white pine blister rust) may have effects on associate species. Efforts to improve wildlife habitat could produce changes through the modification of species composition. Reduction of fire danger through the application of prescribed burning will obviously affect species composition.

Thus, temporal changes that include the cyclical processes of stable communities as well as successional trends that result from the past history of the site provide additional important influences on the species composition of the community, further complicating the reliable inference of understory composition beneath a particular forest overstory.

I.1.2 A BETTER BASIS FOR INFERRING UNDERSTORY SPECIES COMPOSITION

The frequently recognized association of forest understory species with site factors suggests that knowledge of site factors could provide a better basis for inferring understory species composition. topographic, soil, biotic, and climatic variables are all permanent factors of site that, if known, are amenable to storage in a computerized data base as point source or area-wide information [6]. Thus, combinations of site factors could easily be brought to bear on the description of an area in order to take advantage of the greatest possible variety of combinations apt to influence understory species composition.

Elements of overstory information combined with site information could improve the basis for inferring understory species composition. It is possible that understory species composition may be influenced by the general species composition of overstories - perhaps even by the presence or absence of particular species. Another relevant example concerns the frequent dependence of understory species occurrence on overstory density [18]. Because many understory species are adapted to particular levels of illumination beneath the overstory, the combination of overstory density with site information could provide an additional valuable criterion for inferring understory. Periodic re-assessment of overstory density could be rapidly accomplished with remote sensors in a format readily compatible with computer stored site information.

Regions subjected to forest management activities or various natural events are in a state of vegetative transition that may obviate use of the known understory associations with site factors. For these situations, the additional incorporation into the data base of information regarding the dynamic cultural or natural phenomena affecting the site might also provide an improved basis for inferring understory composition within transitional forest communities. It is possible that knowledge of the sequence of successional communities that occur in response to various site factors could be called upon to establish the definition of expected understory associations as a function of the type of and time since a disturbance.

I.2 UNDERSTORY BIOMASS PRODUCTION RELATIONSHIPS TO OVERSTORY AND SITE INFORMATION

Unlike the uncertainties of associating the composition of understories with overstories alone, the relationship between the biomass production of understory vegetation and the density of overstories is much more consistent. For reasons that include competition for light, water, nutrients, and possible antagonistic chemical effects, an increase in overstory tree density generally affects the growth of herbaceous plants beneath them in an adverse manner. Many studies cited by Jameson [30] have illustrated this inverse relationship. Investigators have repeatedly fitted regression lines to their data and proposed mathematical expressions to model the decrease in understory production as a function of such parameters as increasing crown cover, basal area, and depth of overstory tree litter.

Figure I-1 illustrates an example of the typical trend reported in the literature for the relationship between understory production and overstory density. The figure is meant to illustrate that all classes of understory vegetation frequently exhibit the same general trend; relative proportions of each class can vary widely among study areas. The figure also shows that production typically tends to level off under the denser canopies, with little sensitivity to change generally occurring at and beyond intermediate levels of crown closures.

The trend illustrated in Figure I-1 suggests great potential for the role of remote sensors in providing information on understory production. For situations of intermediate to dense overstory, the obvious inference is that understory production is greatly reduced with little variation. For situations of sparse overstory, varying amounts of understory production can be inferred from the pre-determined inverse relationship. However, this relationship indicates only the

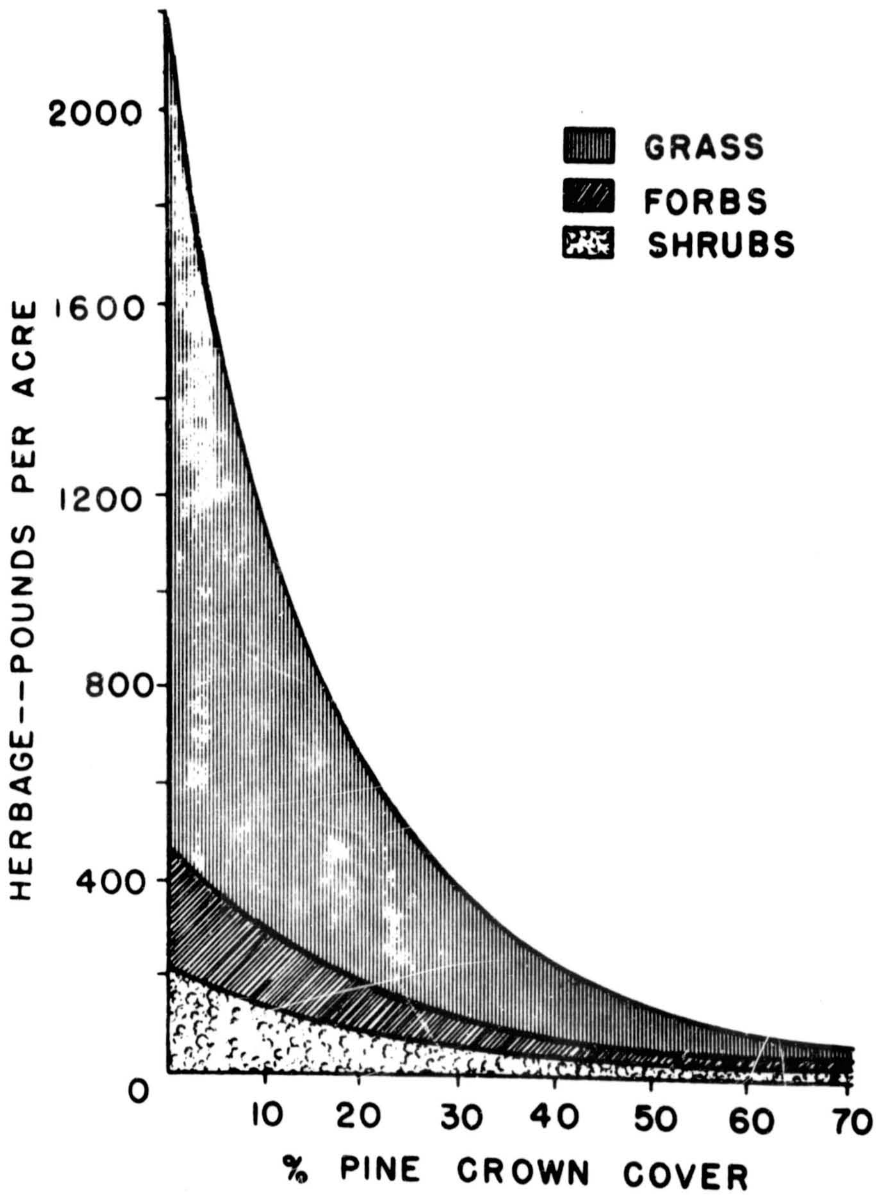


FIGURE I-1. CALCULATED PRODUCTION OF UNDERSTORY VEGETATION AS A FUNCTION OF PINE CROWN COVER [29] potential production from a given site -- the actual production achieved at any given time would depend upon a variety of factors. In many cases, the identification of overstory species composition by remote sensors would likely improve the inference of understory production potential as a function of overstory density.

The potential value for this type of relationship is aptly illustrated by Clary [32] in demonstrating that crown cover information, incorporated as an auxiliary variable in a double sampling technique, can improve the precision for estimating herbage production. Such information, supplied on an area-wide basis by remote sensors, should help the better determination of grazing allotments and assessment of wildlife habitats. Understory production can also be an important information need for other forest management tasks such as watershed management and forest fire control.

The trend illustrated in Figure I-1 is a fortunate one from the standpoint of direct assessment of understory conditions. Understory production varies most for sparse canopy overstory densities that enable the best opportunities for the direct view of understories with remote sensors. Results of this report for forest canopy reflectance modeling have determined that Landsat is most capable of detecting variations in understory conditions for such sparse tree overstory situations only. Thus, variations in understory production that are of greatest importance for resource management decisions occur beneath sparse forest overstories that offer opportunities for both directly assessing as well as inferring understory production potential.

The combination of site information with overstory density should serve to improve the inference of understory production potential since vegetation growth is greatly determined by soil type, soil moisture, and climatic factors. In addition, the past history of the site can have profound influence on understory production.

I-3 CONCLUSIONS

For forested regions, the inference of understory species composition on the basis of remotely sensed overstory properties alone is unreliable. The distributions of vegetation species broadly overlap along environmental gradients according to individual site requirements. In addition, species distributions vary on a time scale according to cyclical processes in stable communities and successional trends of non-stable communities. As a result, vegetation communities are most often comprised of combinations of species populations that are spatially continuous and not entirely consistent in their occurrence from place to place.

Site information may provide a better basis for inferring understory species composition due to the fact that consistent associations have frequently been reported for forest understory species and local site factors. The inference may improve with the addition of general overstory species composition and overstory density information since the occurrence of many understory species can be influenced by such factors. Remote sensors offer the potential for rapid, periodic reassessments of overstory density and composition.

The generally consistent relationship between understory biomass production and overstory density indicates that potential exists for inferring understory production capability on the basis of overstory density within various forest cover types. The obvious inference of little or no understory production can be made for situations of intermediate to dense overstories. For sparse overstory situations, a predetermined inverse relationship can enable inference of varying understory production potential. In addition, sparse overstory situations enable the best opportunities for the direct view of understory situations. Thus, remote sensors can potentially serve a valuable role for providing area-wide information on understory production on an indirect basis by assessing overstory density within various forest cover types and by directly viewing understories beneath sparse canopies. The addition of site information is likely to improve the assessment of understory production since local site factors as well as natural and man-caused disturbances affect understory production.

The combination of both site information and overstory density provided by remote sensors into a common data base could provide the best means for utilizing both types of information in order to increase the knowledge of forest understories that is required for resource management decisions.

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